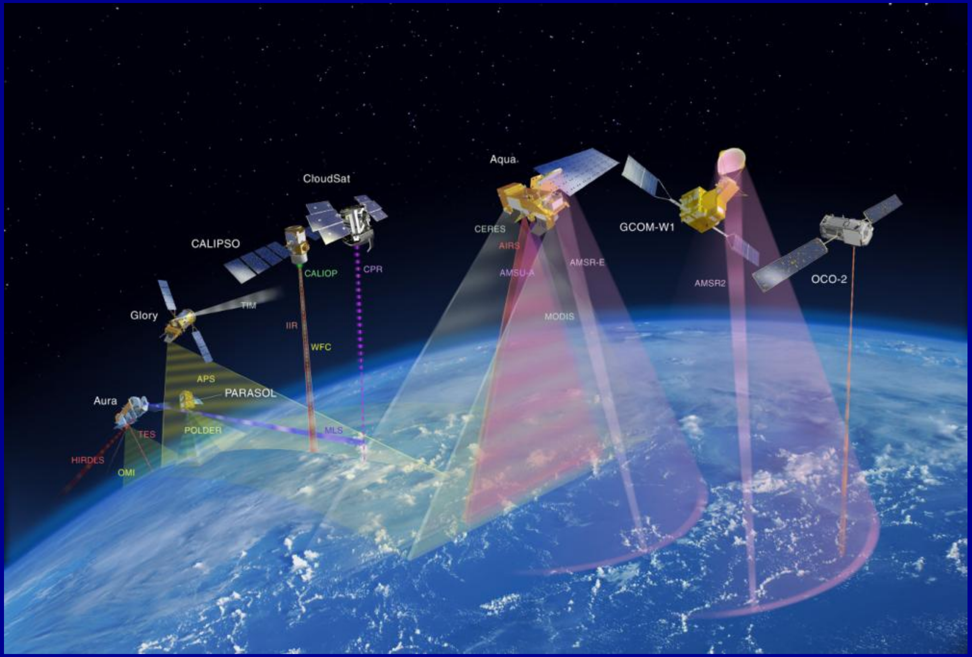
Influence of Clouds and Aerosols on the Earth's Radiation Budget Through Synergistic Use of A-Train Observations



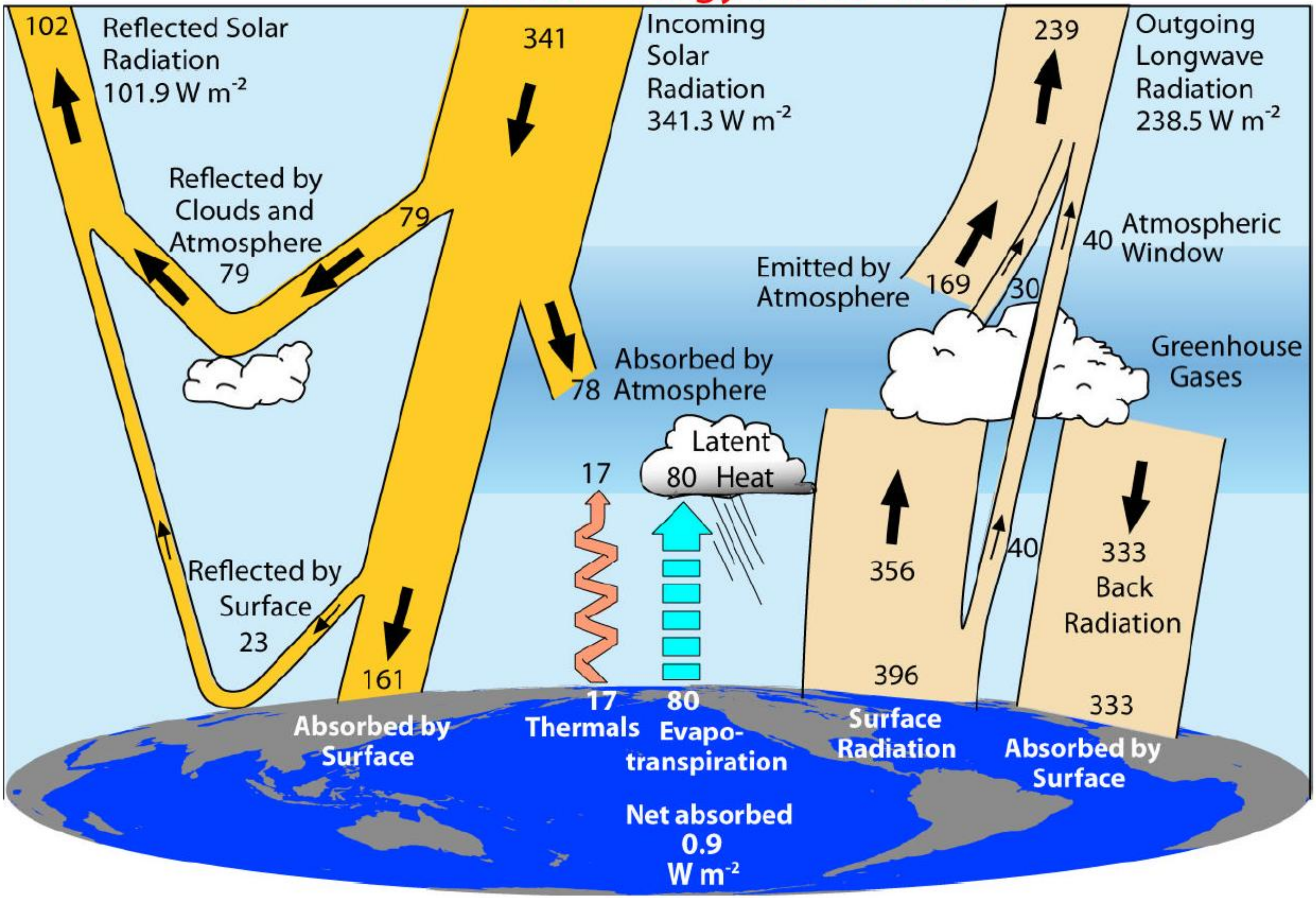
Norman G. Loeb, S. Kato – NASA Langley Research Center, Hampton, VA
W. Su, F.G. Rose, D.A. Rutan – SSAI, Hampton, VA
E. Wilcox – Desert Research Institute, Reno, NV

A-Train Symposium, Oct 25-28, 2010, New Orleans, LA

Outline

- Introduction
- Lessons Learned About Surface Downward Longwave Radiation From A-train Observations.
- Exploration of Recent Interannual Climate Variations with EOS & A-train Observations.
- Quantifying Direct & Semi-Indirect Radiative Effects of Aerosols with A-train Observations

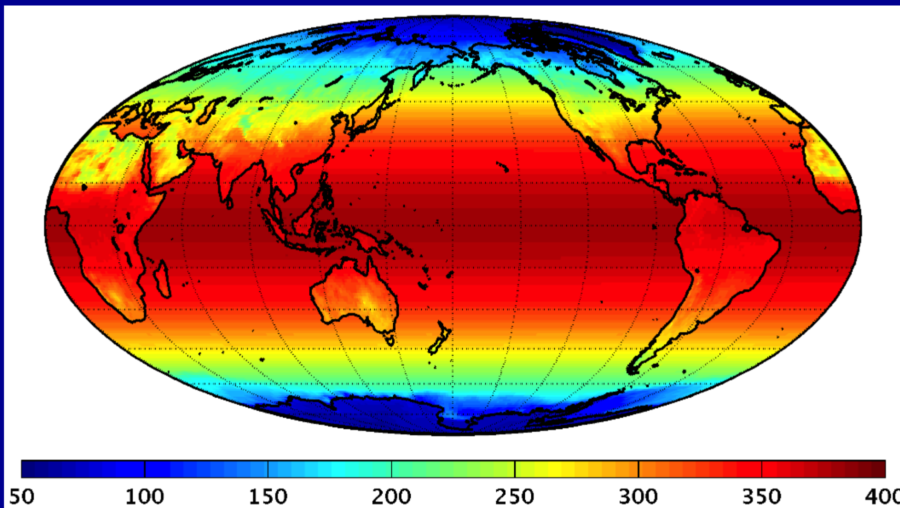
Global Energy Flows W m^{-2}



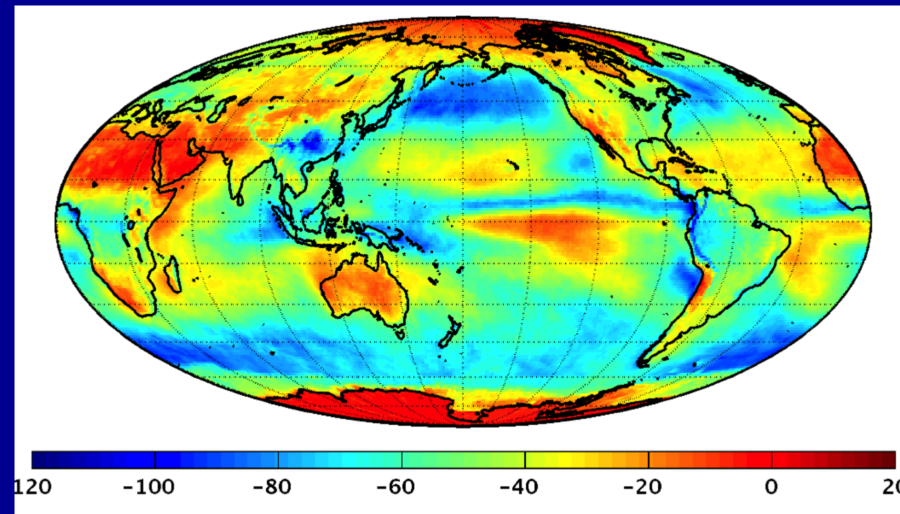
Trenberth et al., 2009

Net Downward Shortwave Radiation at Top-of-Atmosphere (CERES)

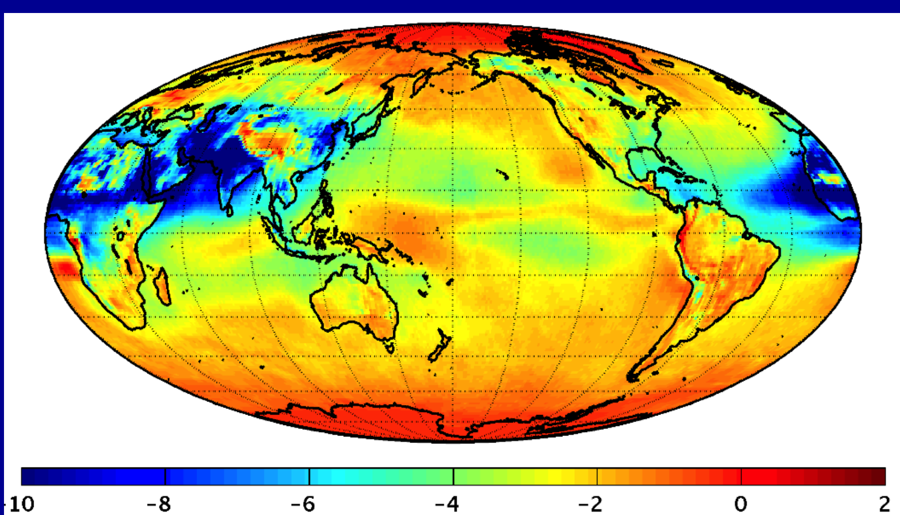
No Aerosols; No Clouds (291 Wm^{-2})



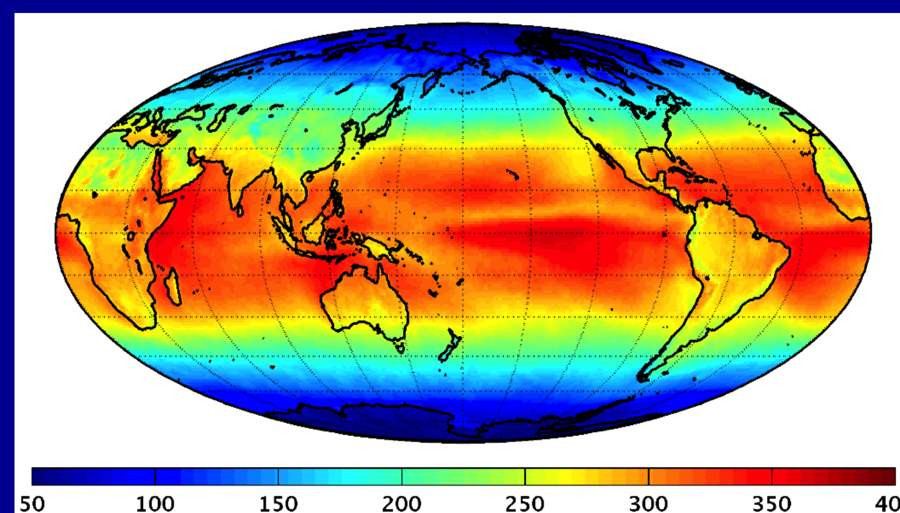
Cloud Radiative Effect (-47 Wm^{-2})



All-Sky Aerosol Direct Radiative Effect (-3 Wm^{-2})

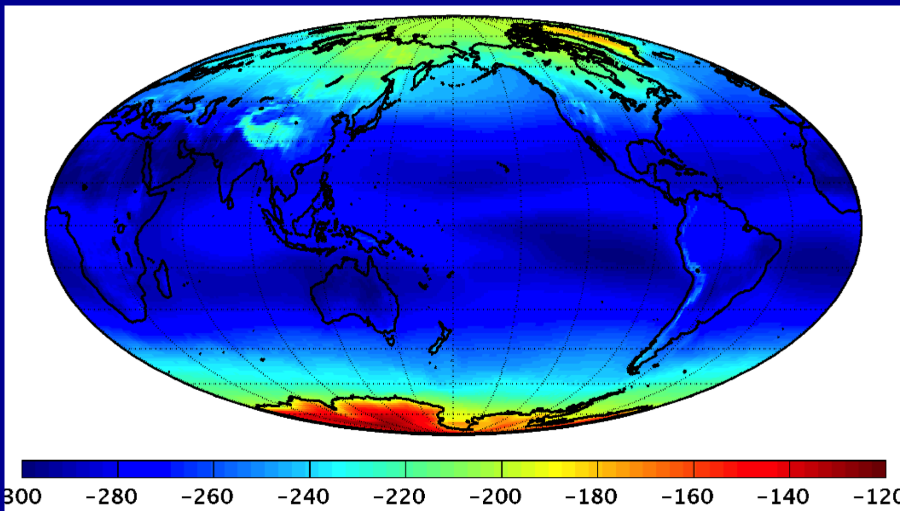


All-Sky (241 Wm^{-2})

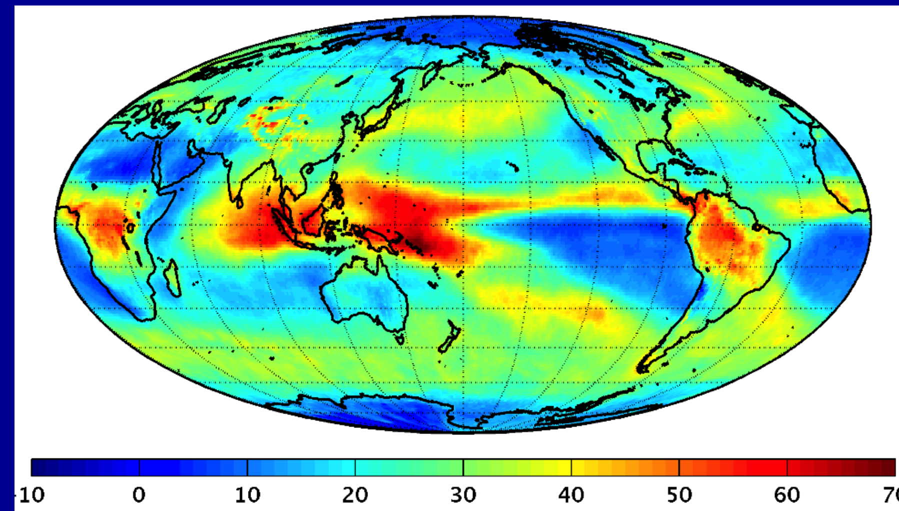


Net Downward Longwave Radiation at Top-of-Atmosphere (CERES)

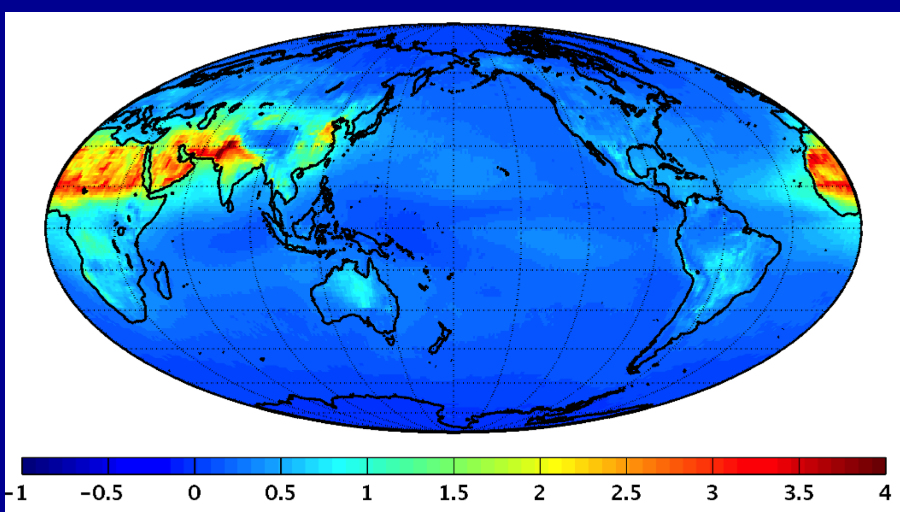
No Aerosols; No Clouds (-267 Wm^{-2})



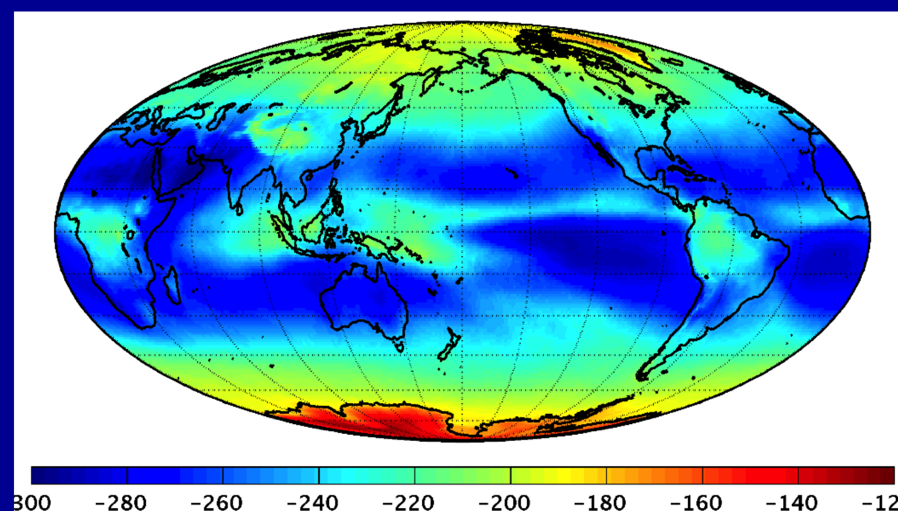
Cloud Radiative Effect (27 Wm^{-2})



All-Sky Aerosol Direct Radiative Effect (0.4 Wm^{-2})

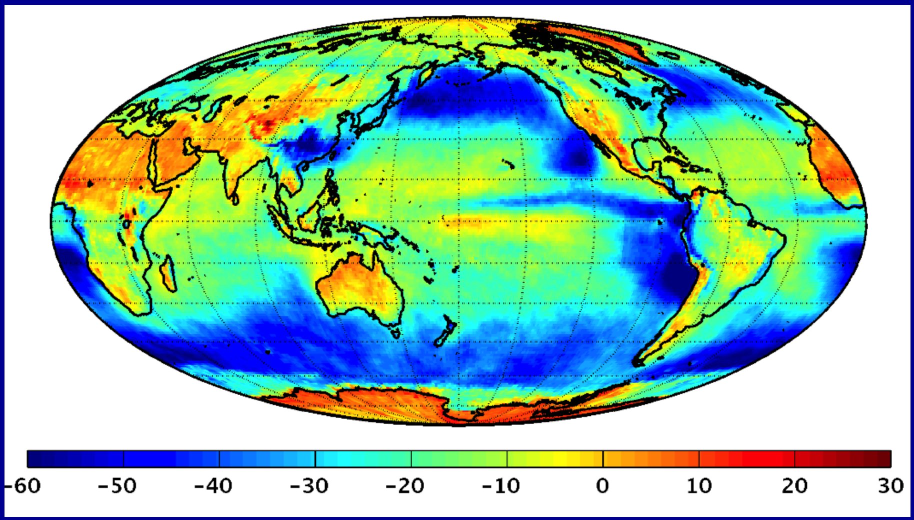


All-Sky (-240 Wm^{-2})

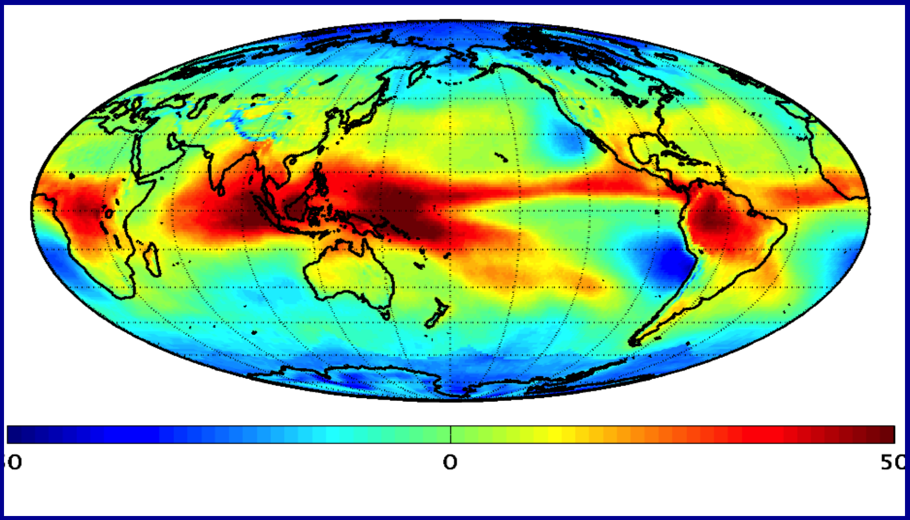


Net Cloud Radiative Effect (TOA, ATM, SFC) (CERES)

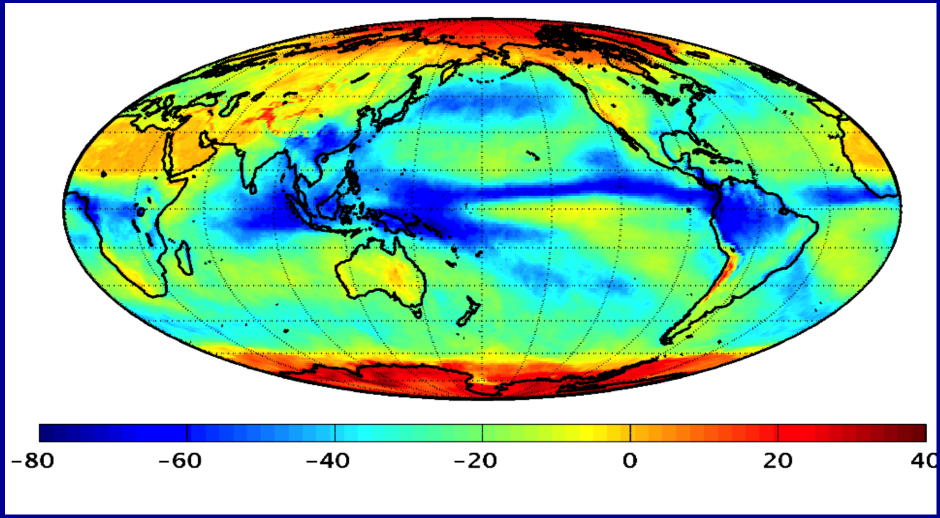
Top-of-Atmosphere (-20.6 Wm^{-2})



Within-Atmosphere (2 Wm^{-2})



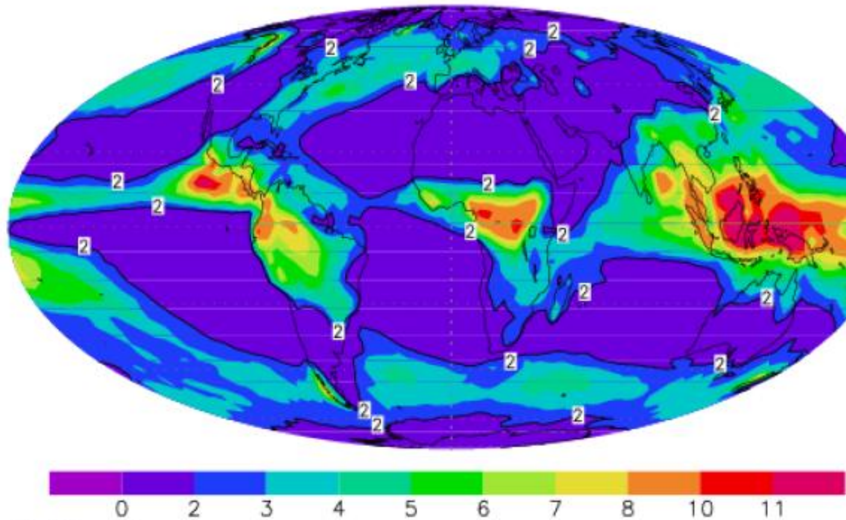
Surface (-22.3 Wm^{-2})



- **High Clouds**
  - SW & LW CRE cancel at TOA (both large).
  - SW CRE (cooling) dominates at SFC.
  - Positive within-atmos net CRE (warming).
- **Low Clouds**
  - SW CRE (cooling) dominates at TOA.
  - SW & LW CRE cancel at SFC (both large).
  - Negative within-atmos net CRE (warming).

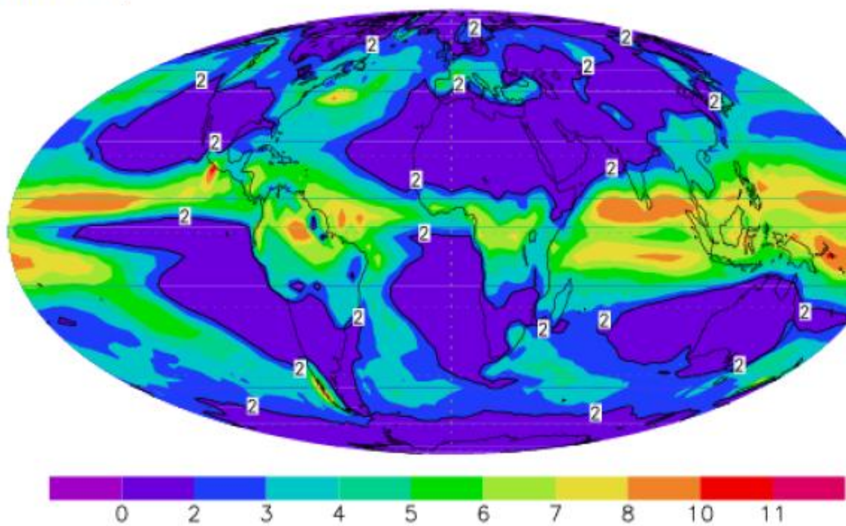
Impact of the atmospheric cloud radiative forcing on GCM-simulated tropical circulation

CRF ON

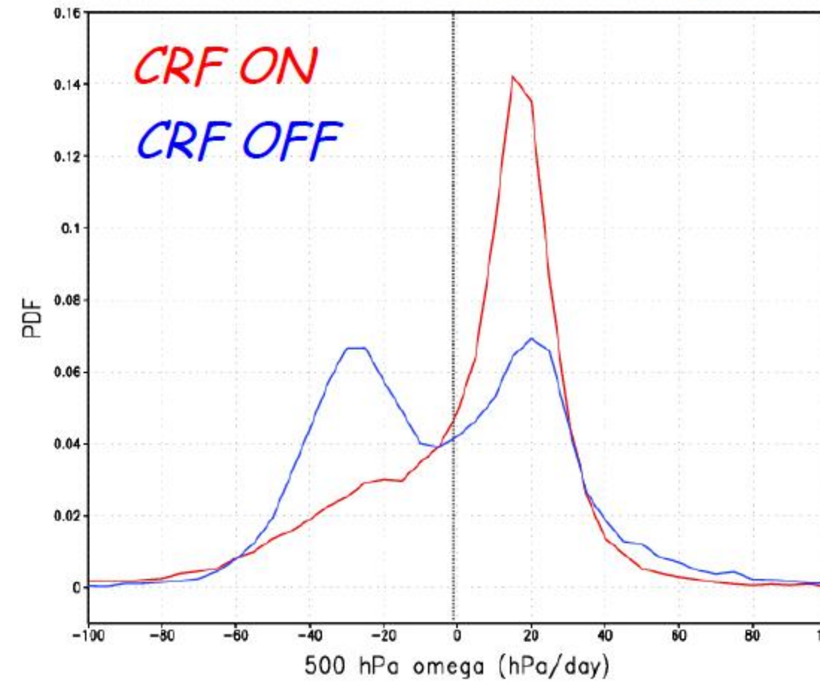


Precipitation (mm/d)

CRF OFF



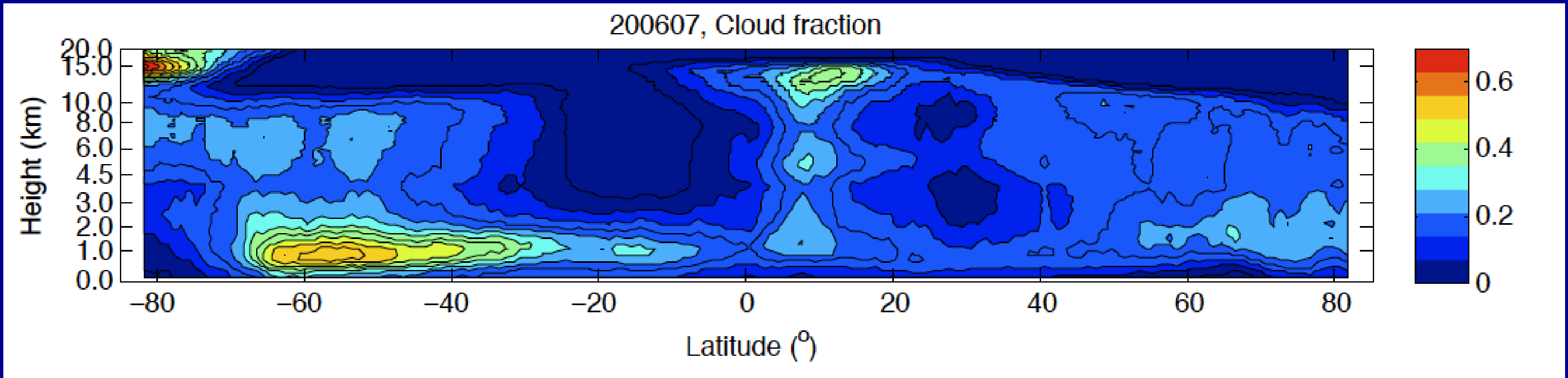
PDF of 500hPa omega

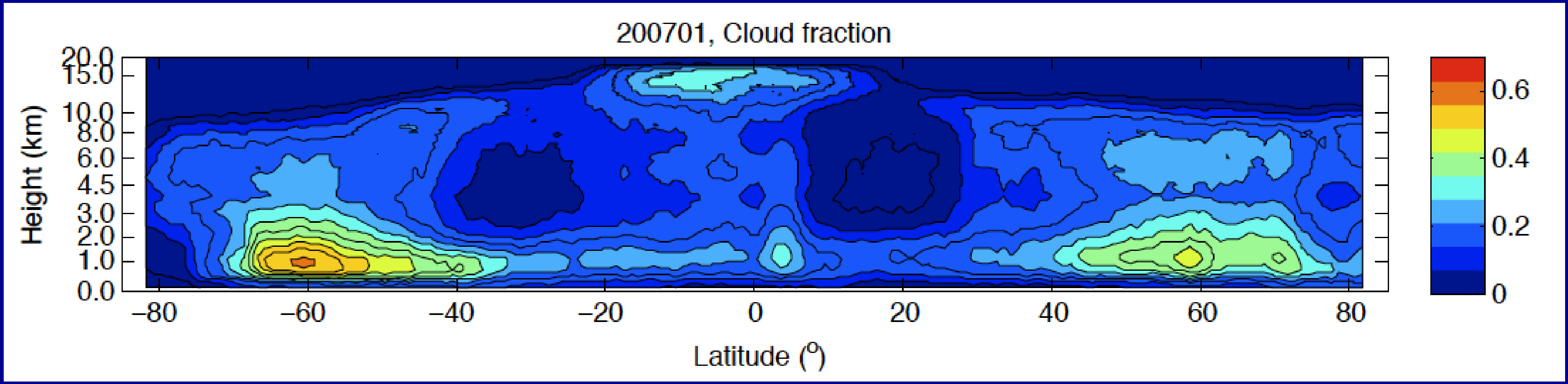


Cloud-radiative effects strengthen the Hadley-Walker circulation and make the ITCZ more narrow

Bony, 2007

Cloud profile from CALIPSO and CloudSat



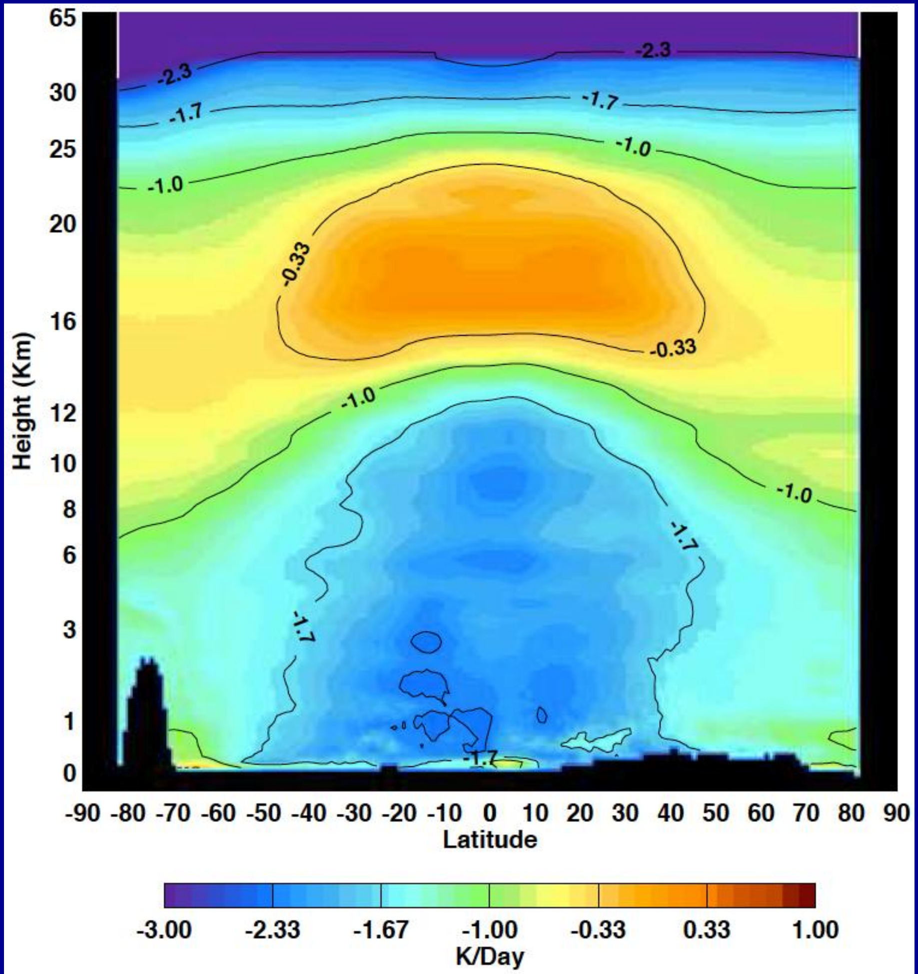


Cloud fraction in a 200 m by 1 degree volume

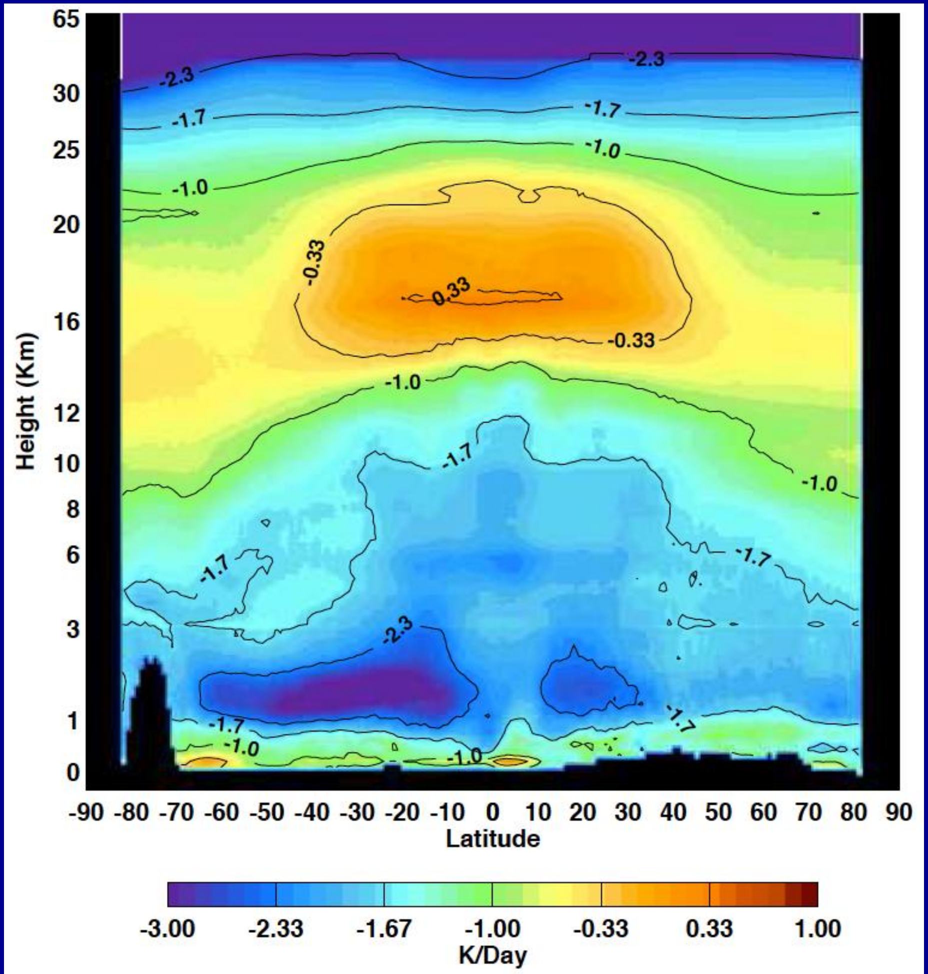
Seiji Kato

CALIPSO/Cloudsat/CERES/MODIS (CCCM) Annual and Zonal Mean Vertical Distribution of Longwave Atmospheric Heating Rate

Clear-Sky

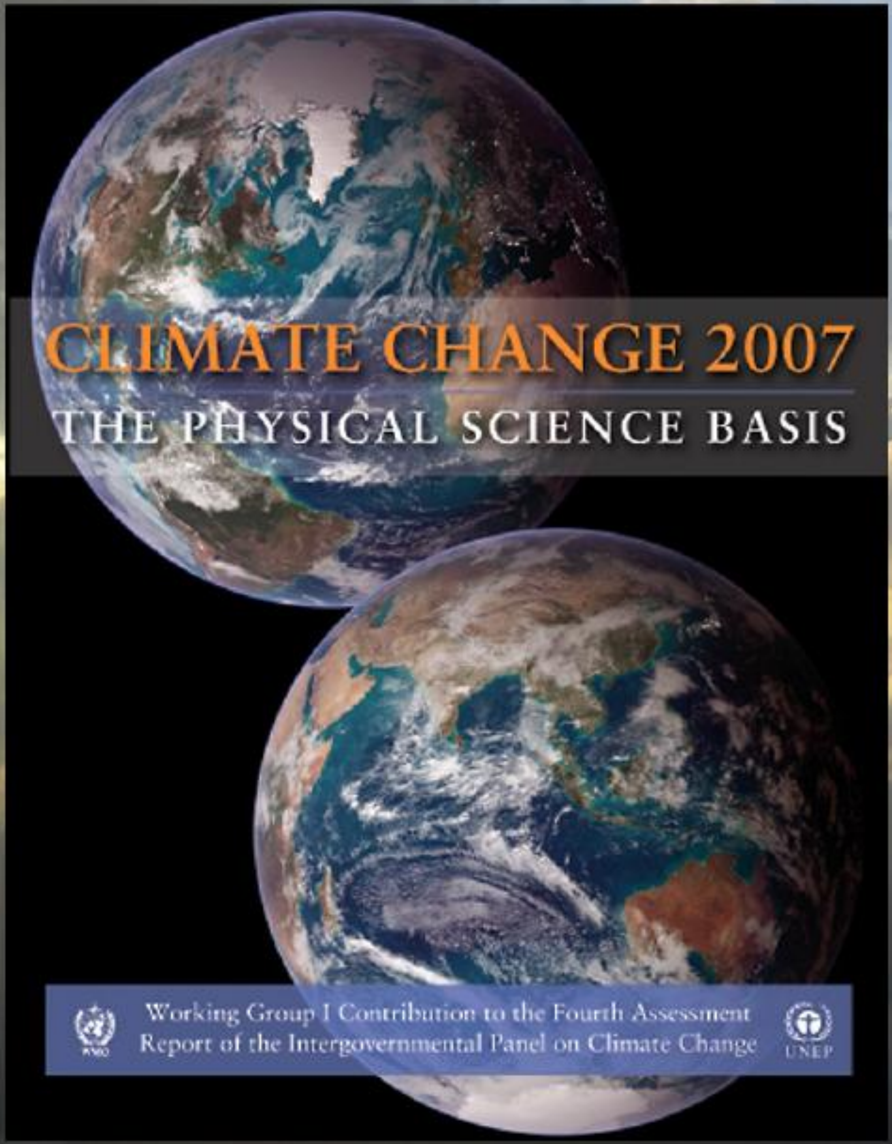


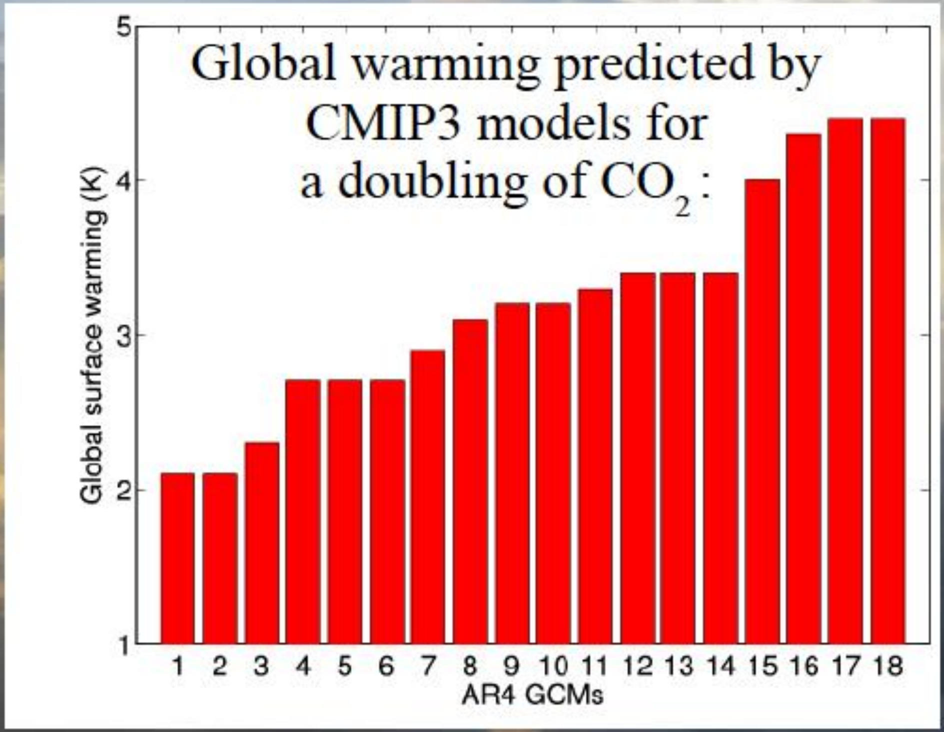
All-sky



Seiji Kato

Uncertainty on climate sensitivity





Randall et al., IPCC 2007

The response of marine boundary-layer clouds has been pointed out as a primary contributor to inter-model differences in climate sensitivity (Randall et al., IPCC 2007).

However :

- Clouds do not matter only for climate sensitivity !
- PBL clouds are not the only clouds to be critical for climate modelling !

Satellite Observations-CMIP5-IPCC AR5
The Earth System Grid

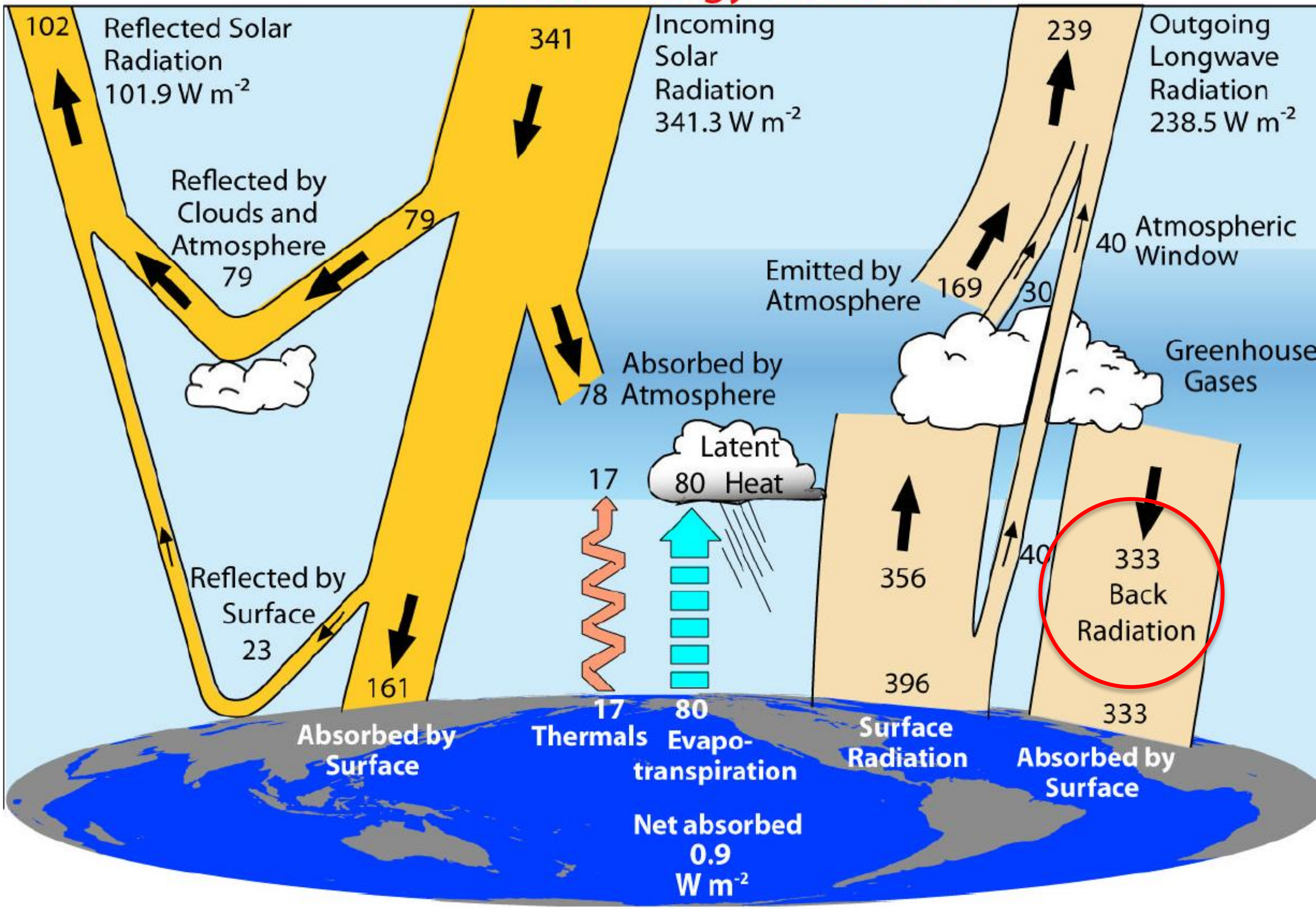
What if?

- there was a resource dedicated to disseminating selected NASA products for baseline model evaluation via:
    - ESG access to the individual products, and perhaps also *bundled*
    - A report series for the envisaged technical notes
- **PCMDI, major modeling centers, and a very large community of scientists involved in model evaluation would jump on this resource! And be able to cite it!**

Peter J. Gleckler, LLNL (Oct 12, 2010)

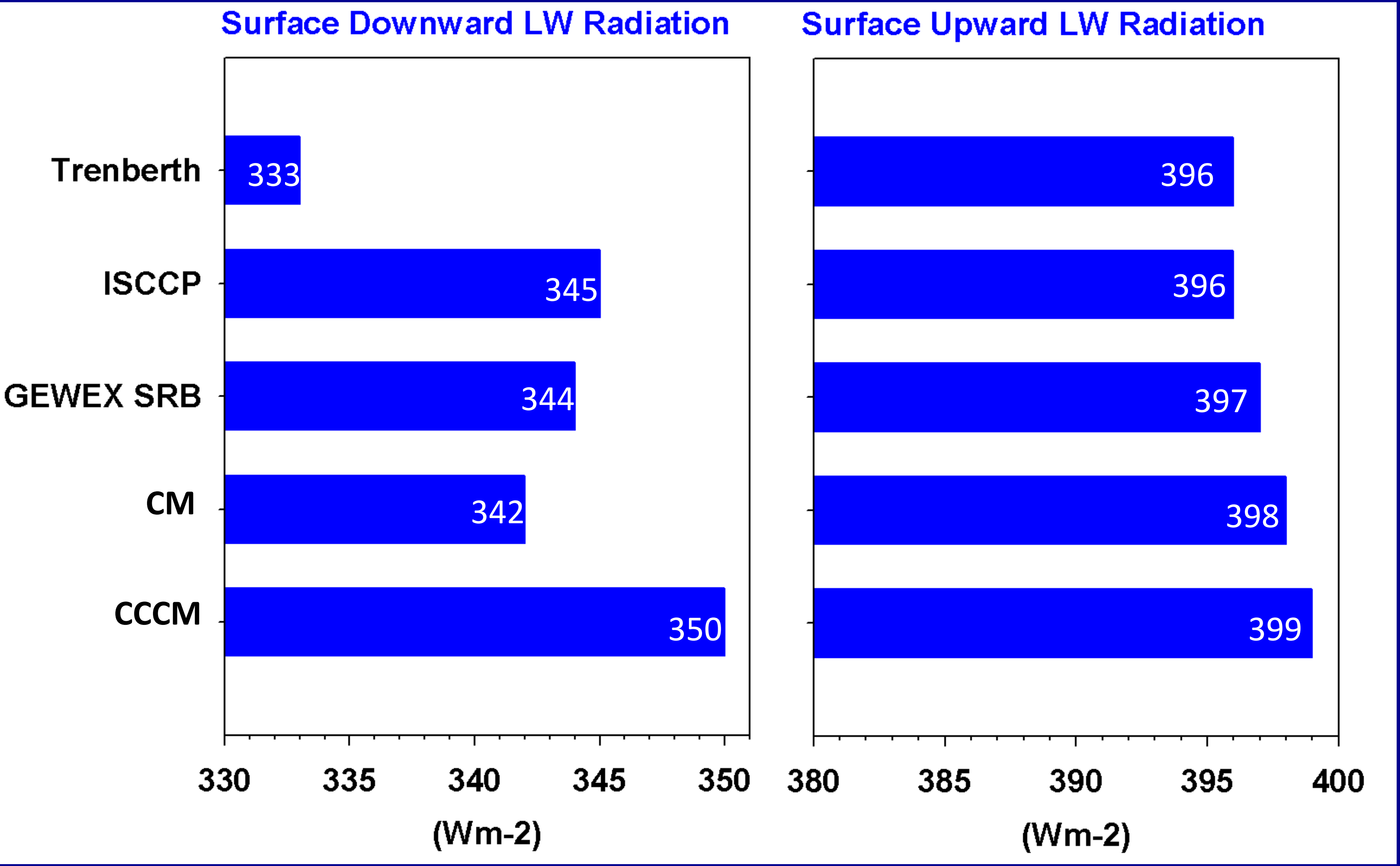
Lessons Learned About Earth Radiation Budget From A-train Observations

Global Energy Flows W m^{-2}



Trenberth et al., 2009

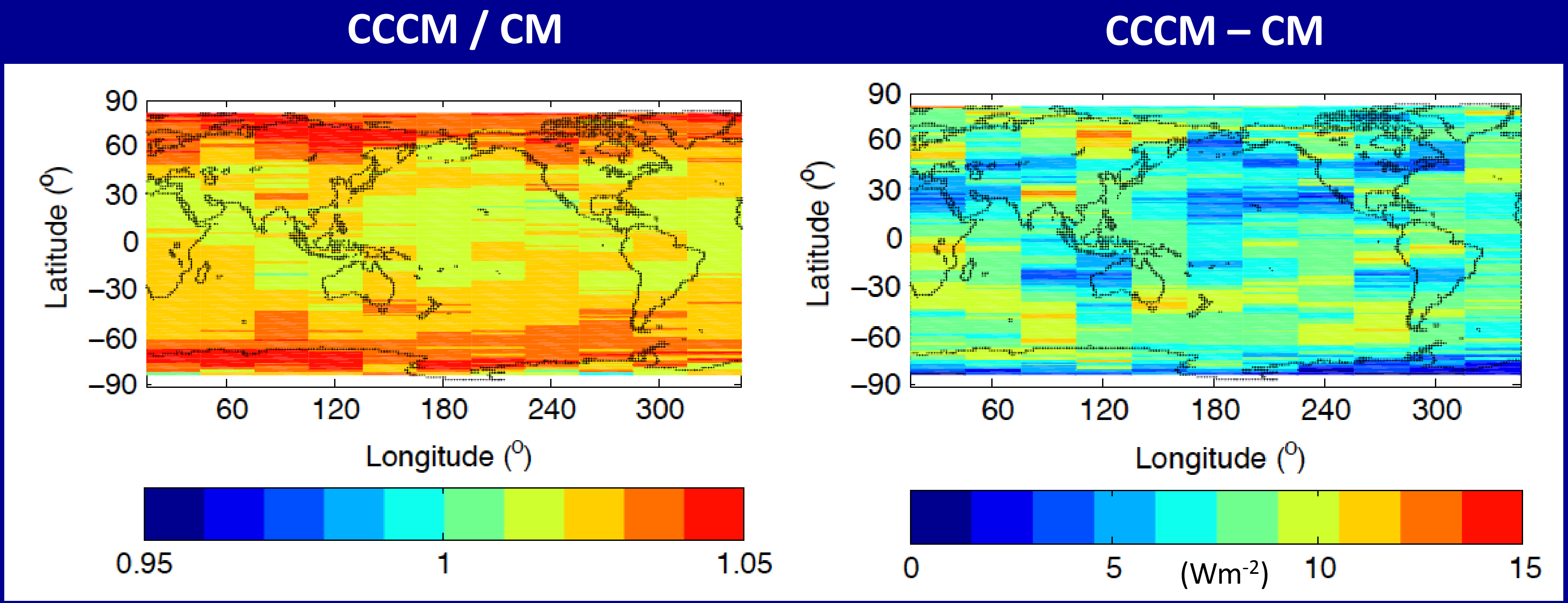
Global Mean LW Radiation at the Surface



CM = CERES/MODIS

CCCM = CALIPSO/Cloudsat/CERES/MODIS

Surface Downward Longwave Radiative Flux Difference (Annual Mean)

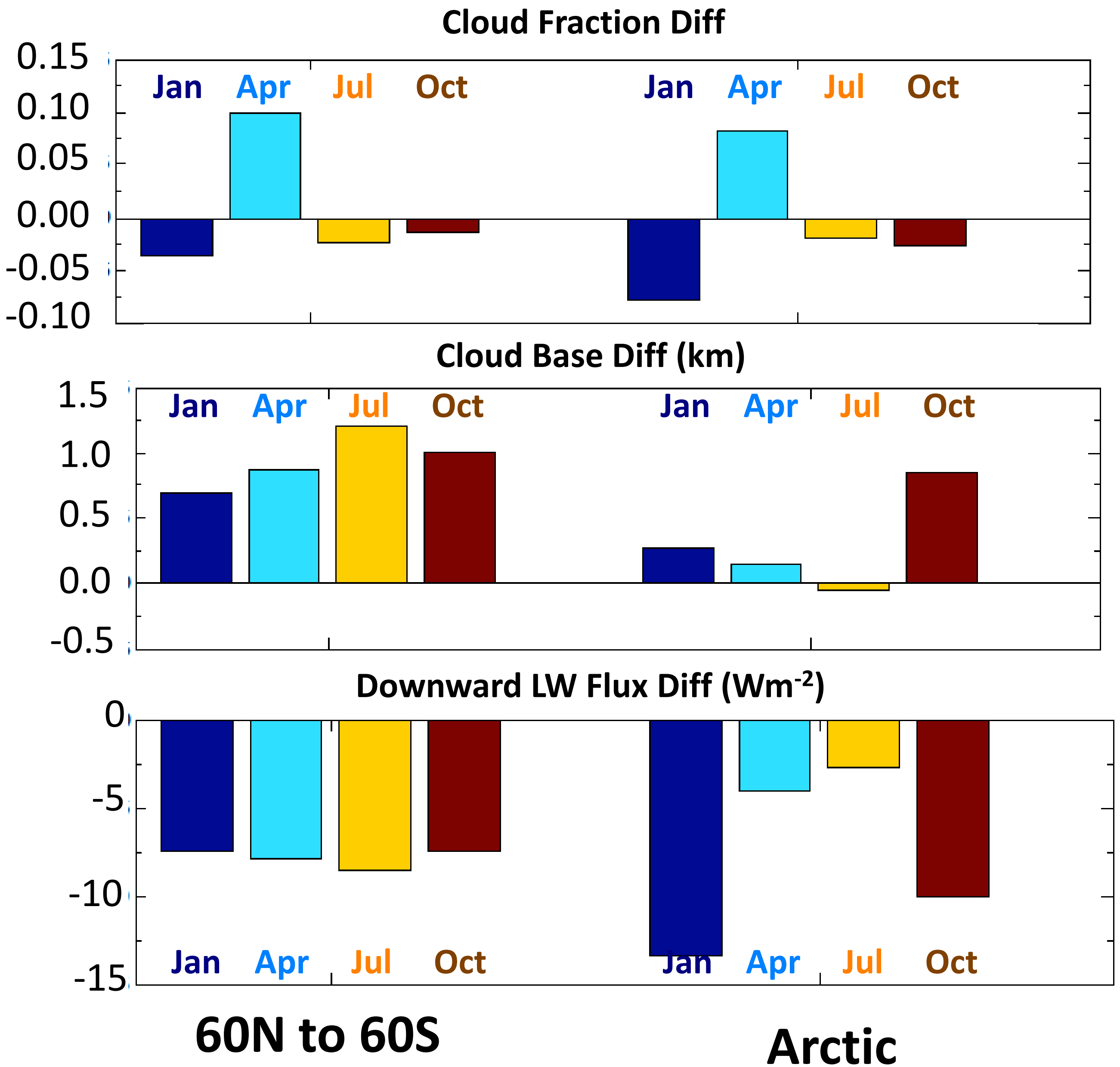


CM = CERES/MODIS

CCCM = CALIPSO/Cloudsat/CERES/MODIS

Seiji Kato

CM minus CCCM Difference in:
Cloud Fraction, Cloud Base, and SFC Downward LW Radiation



60°S-60°N

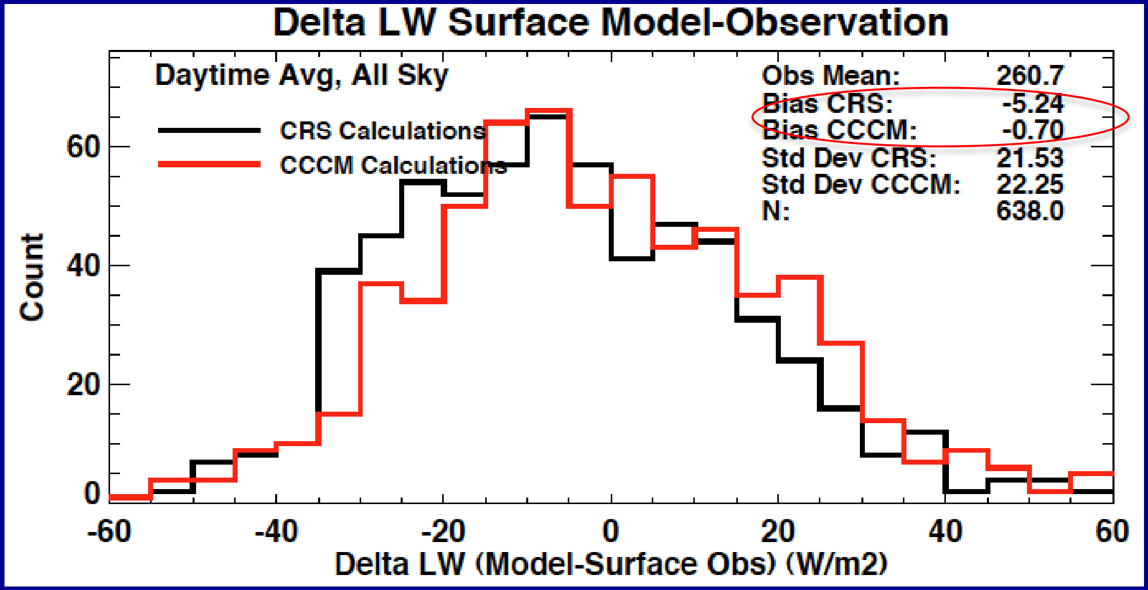
- LW downward biased low because cloud base is too high in MODIS.

Arctic

- LW downward biased low during winter (polar night) due mainly to under-estimation of cloud fraction.

Ground Validation of Downward LW Radiation in Arctic (July 2006 through Dec. 2008)

Daytime
Spring
Summer
Fall



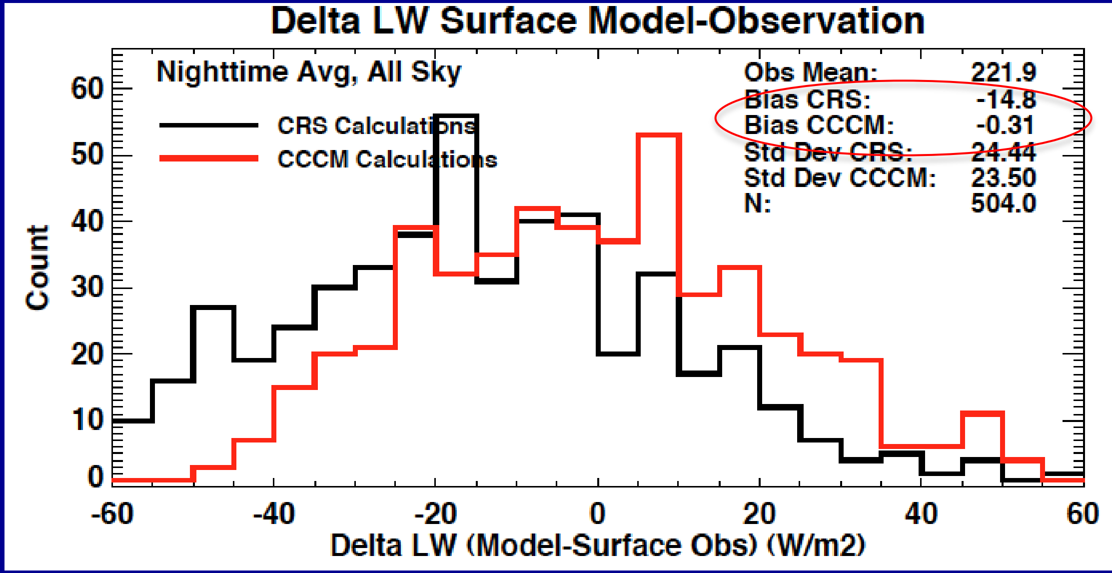
Surface sites

NYA - Ny Alesund Norway (78.93N, 11.95E)

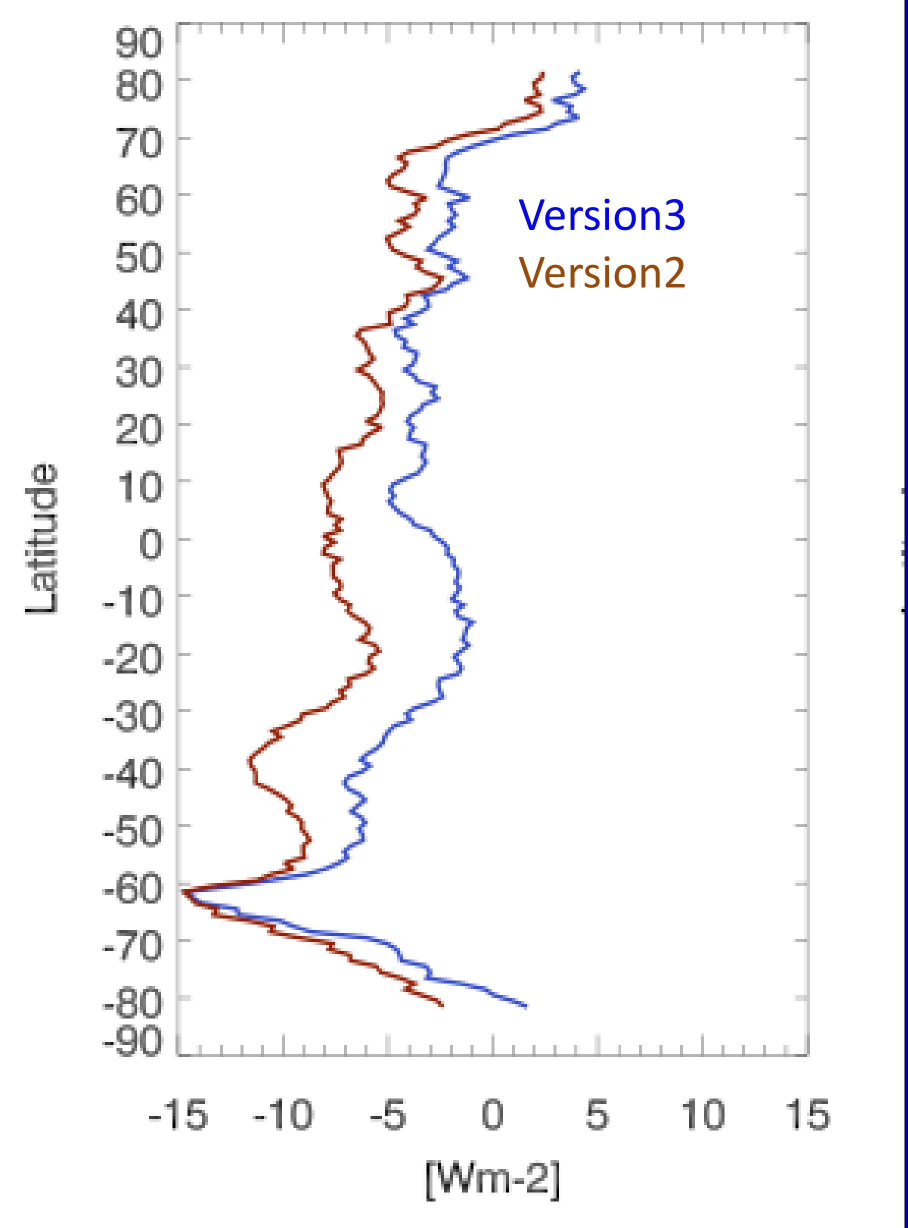
BAR - Barrow Alaska (71.32N, 156.61W)

ALT - Alert, Canada (82.51N, 62.35W)

Nighttime
Fall
Winter
Spring



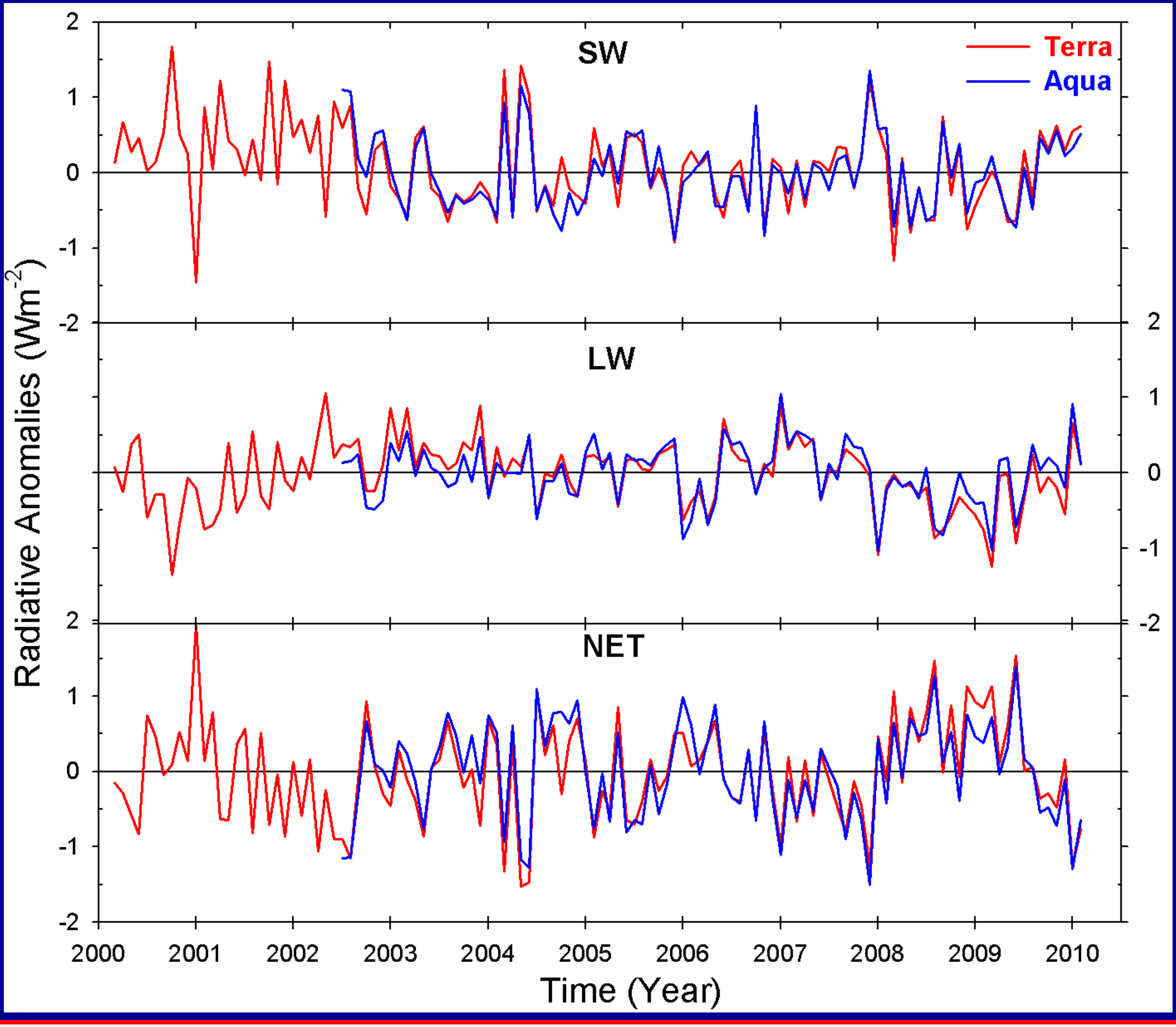
All-sky Surface Downward LW Radiative Flux Difference
CM minus CCCM, July 2008



CALIPSO V. 3	CALIPSO V. 2
-3.6	-6.9

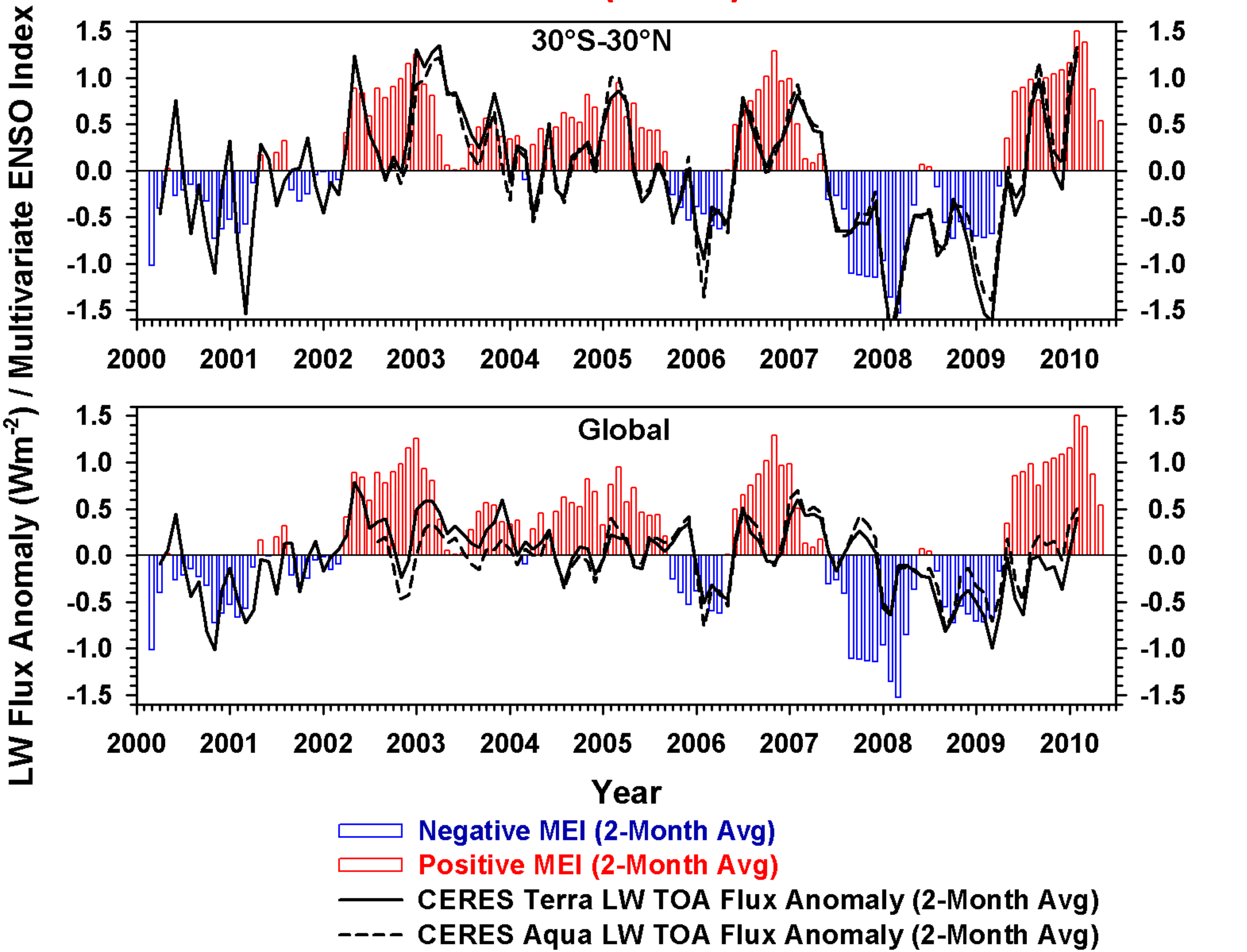
Exploring Interannual Variations with EOS & A-train Observations

Global CERES Top-of-Atmosphere Radiation Anomalies (CERES)

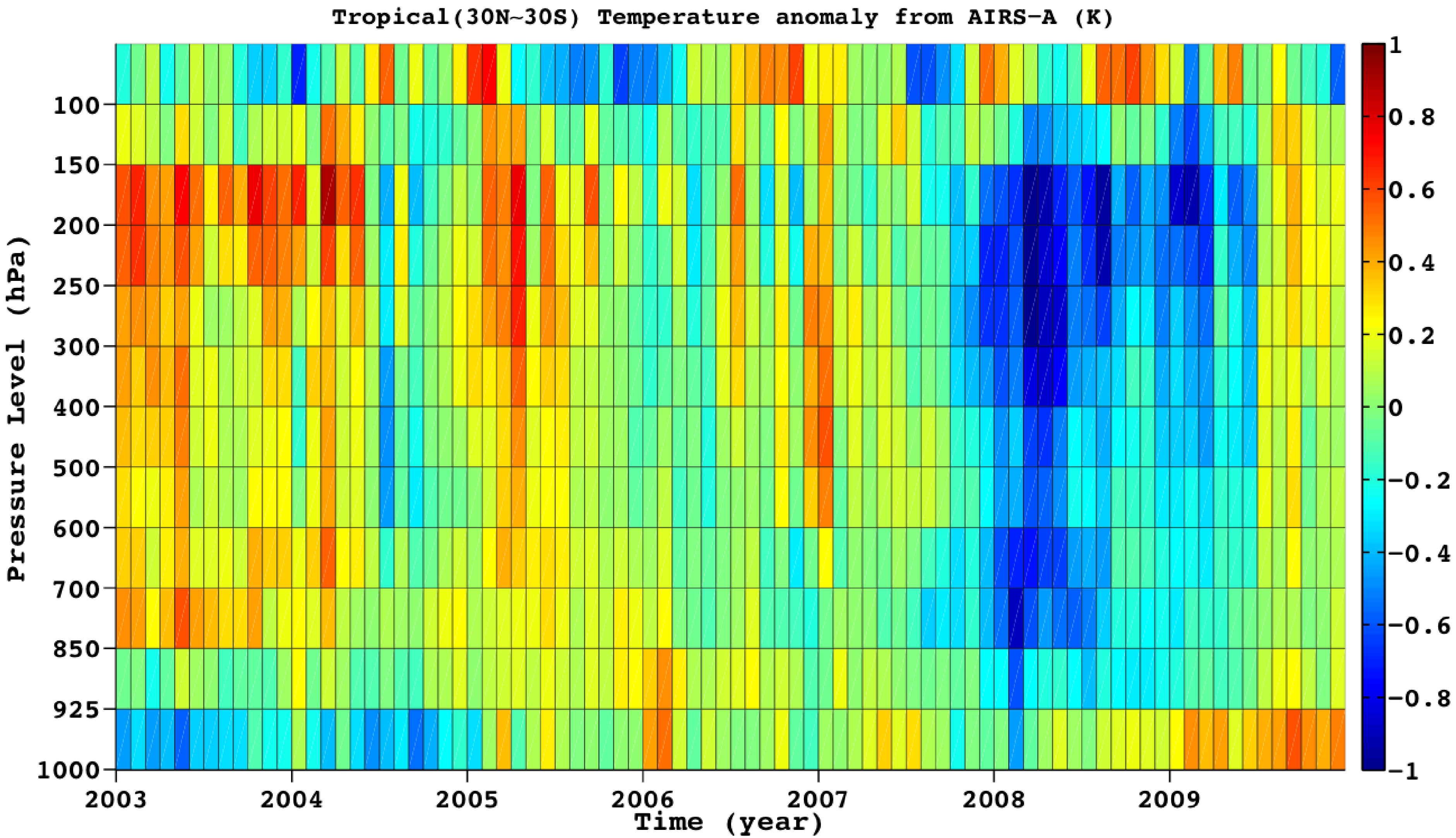


CERES is providing the first decadal global climate data record of the Earth's Radiation Budget at climate accuracy from broadband instruments.

LW Radiation Anomalies (CERES) and ENSO Index

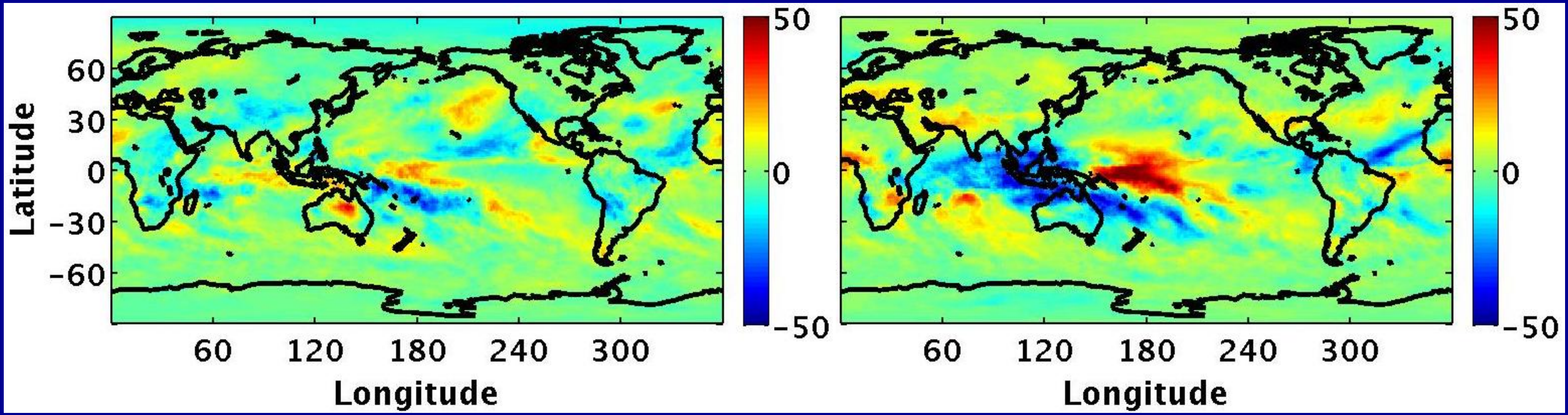


AIRS Temperature Anomaly (30°S-30°N)

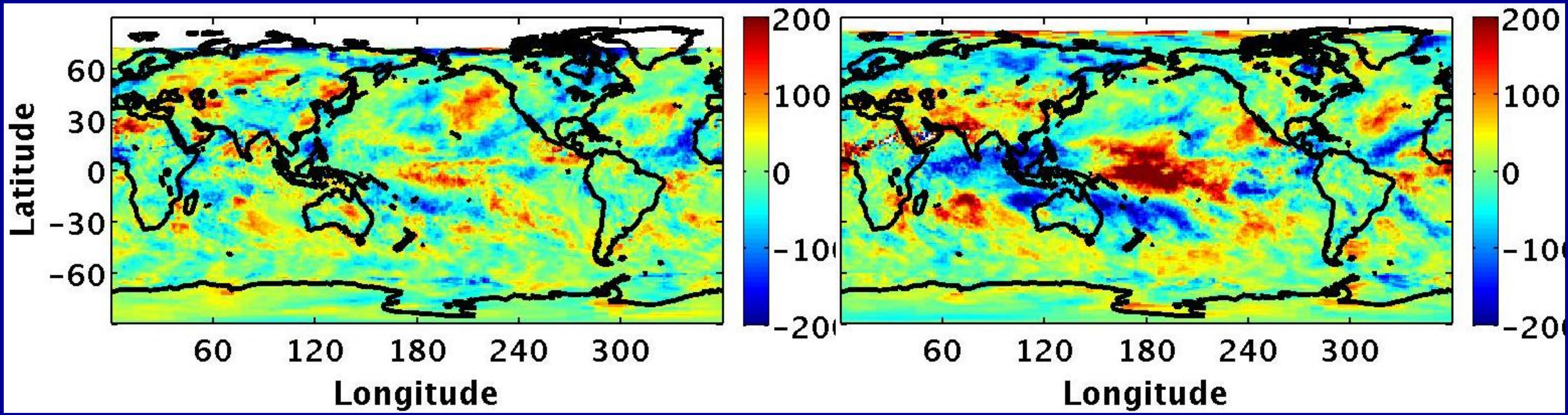


CERES LW TOA Flux and MODIS Cloud Top Pressure Anomalies

January 2008 **CERES LW TOA Flux Anomaly (Wm^{-2})** February 2008

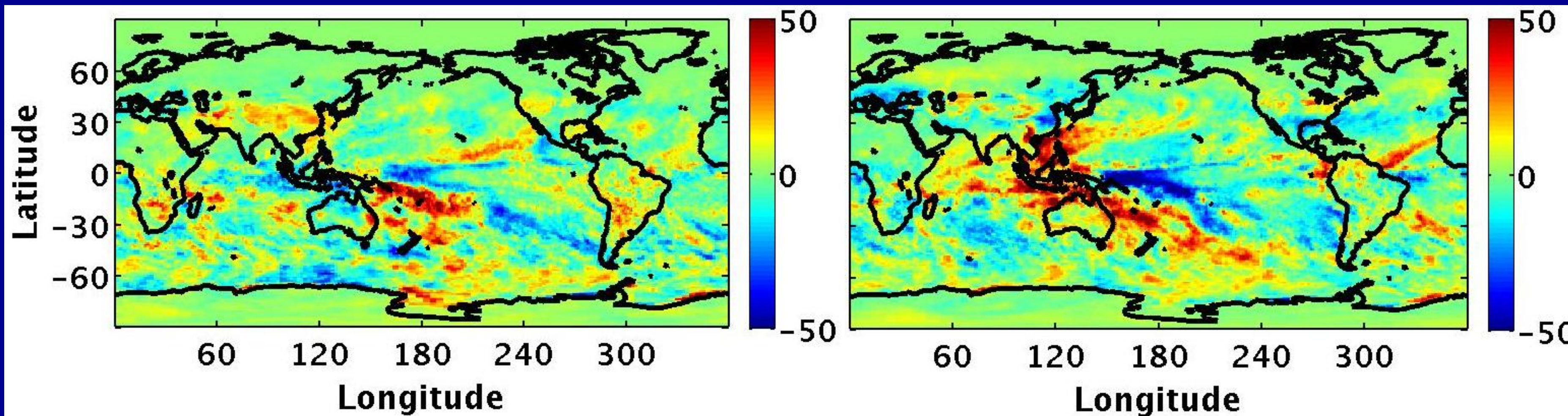


January 2008 **MODIS Cloud Top Pressure Anomaly (hPa)** February 2008

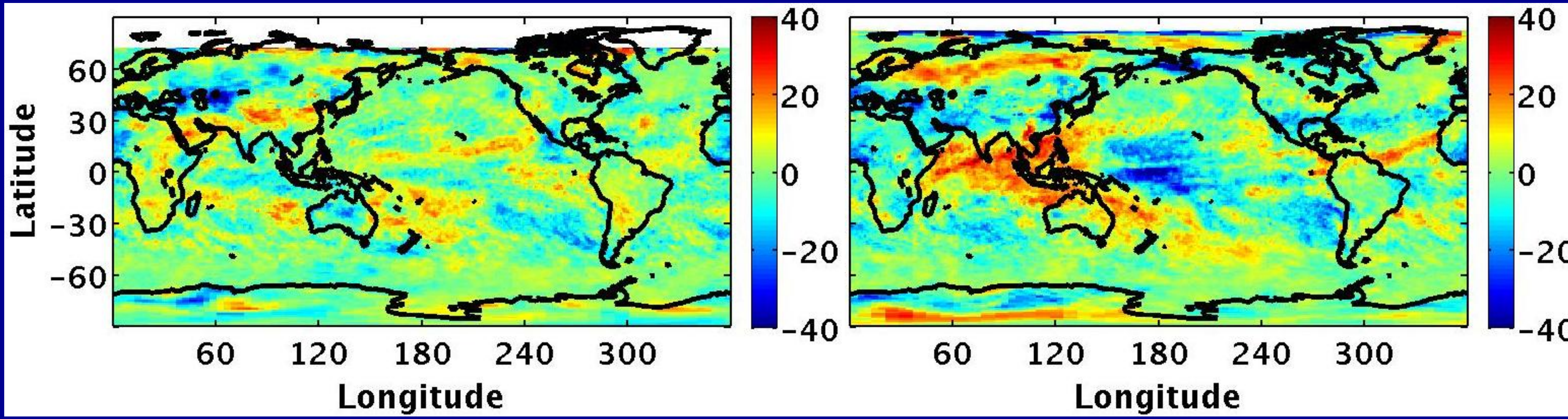


CERES SW TOA Flux and MODIS Cloud Fraction Anomalies

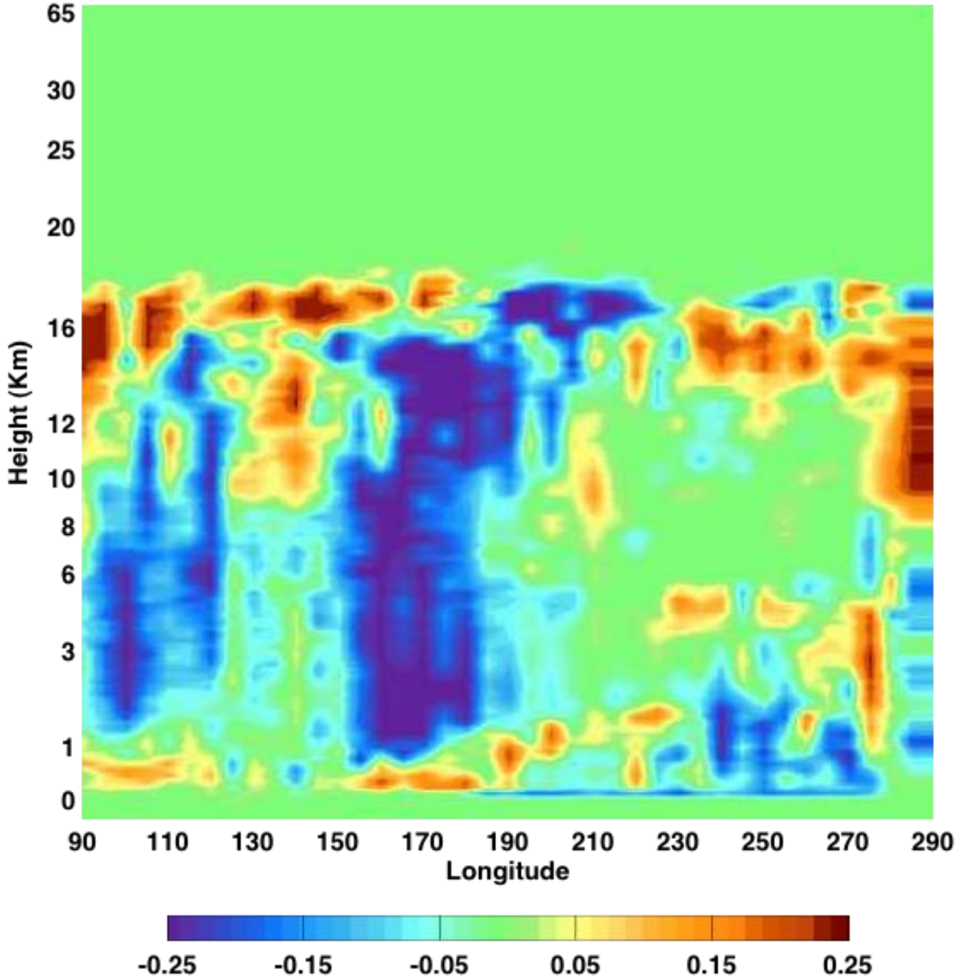
January 2008 **CERES SW TOA Flux Anomaly (Wm^{-2})** February 2008



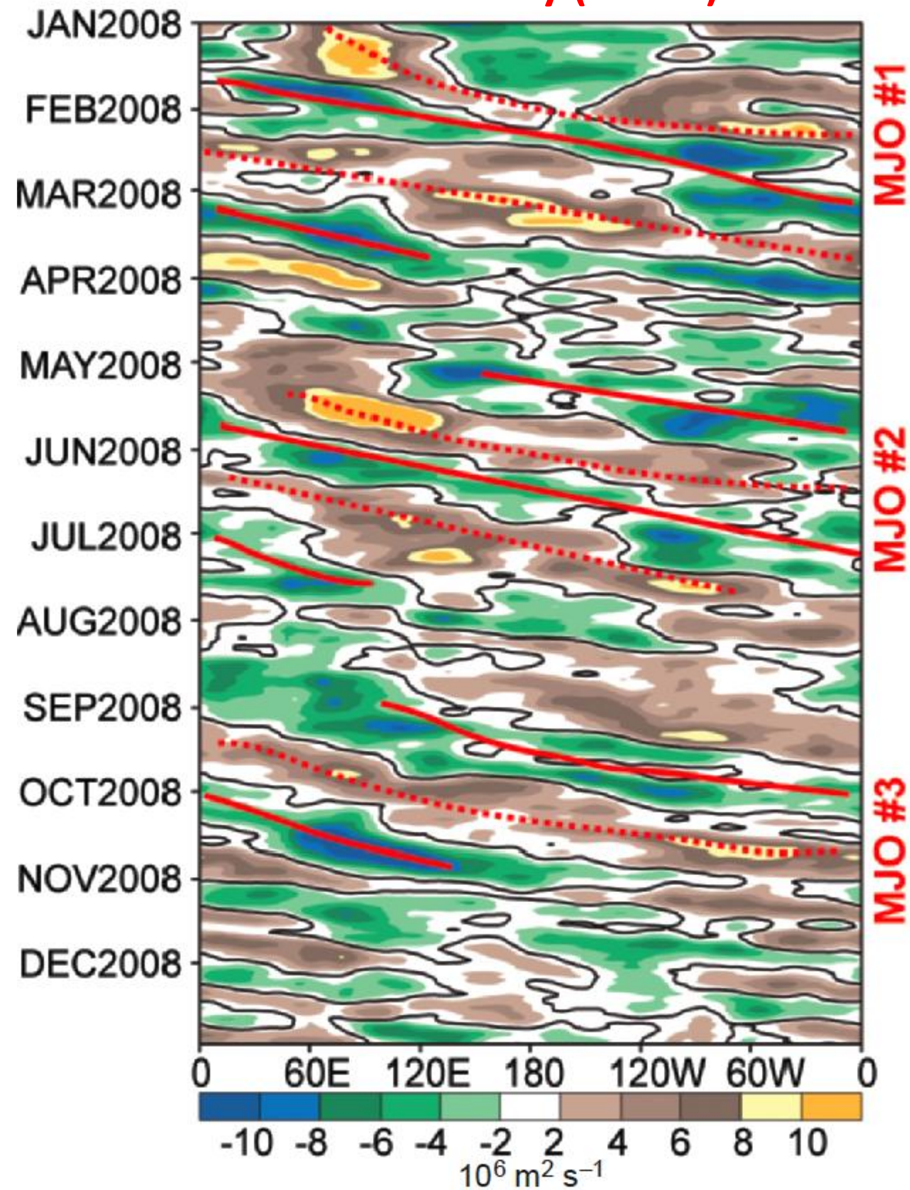
January 2008 **MODIS Cloud Fraction Anomaly (%)** February 2008



CALIPSO/Cloudsat Cloud Frequency of Occurrence Difference
Jan08 minus Jan07 (0S–2.5S)

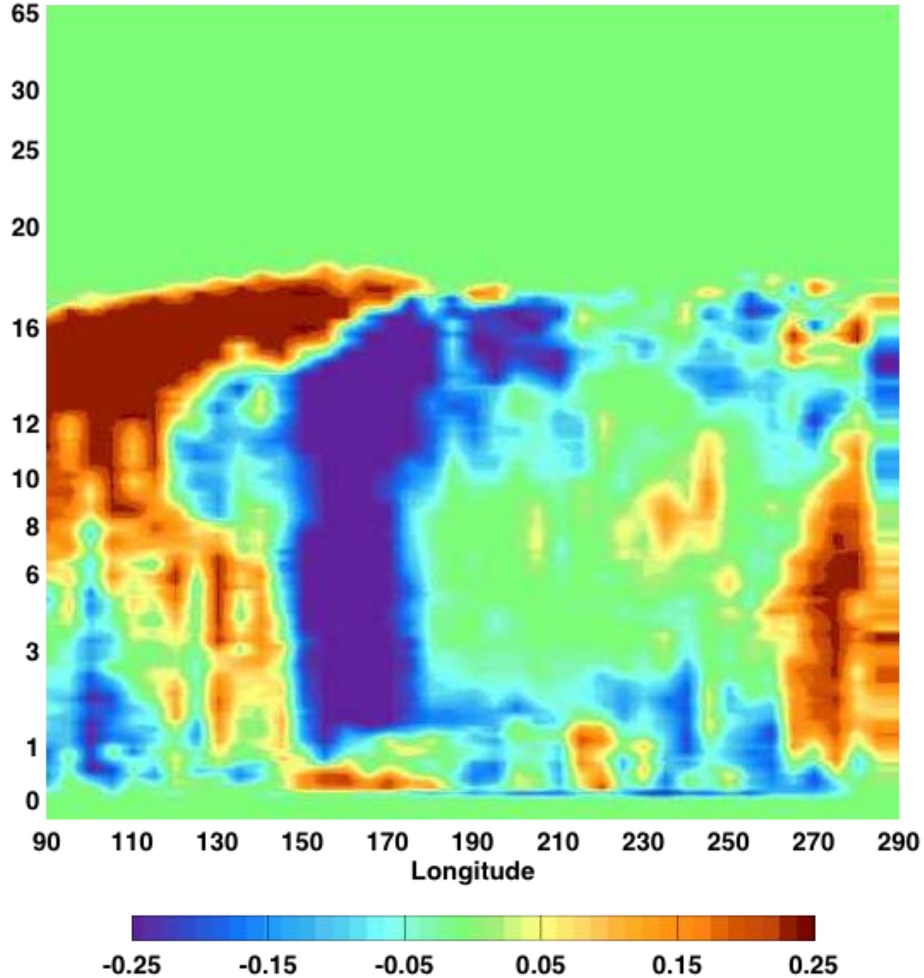


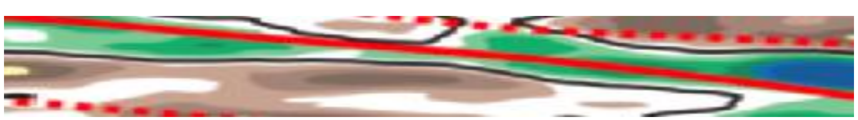
Filtered 200-hPa Velocity Potential Anomaly (5S–5S)



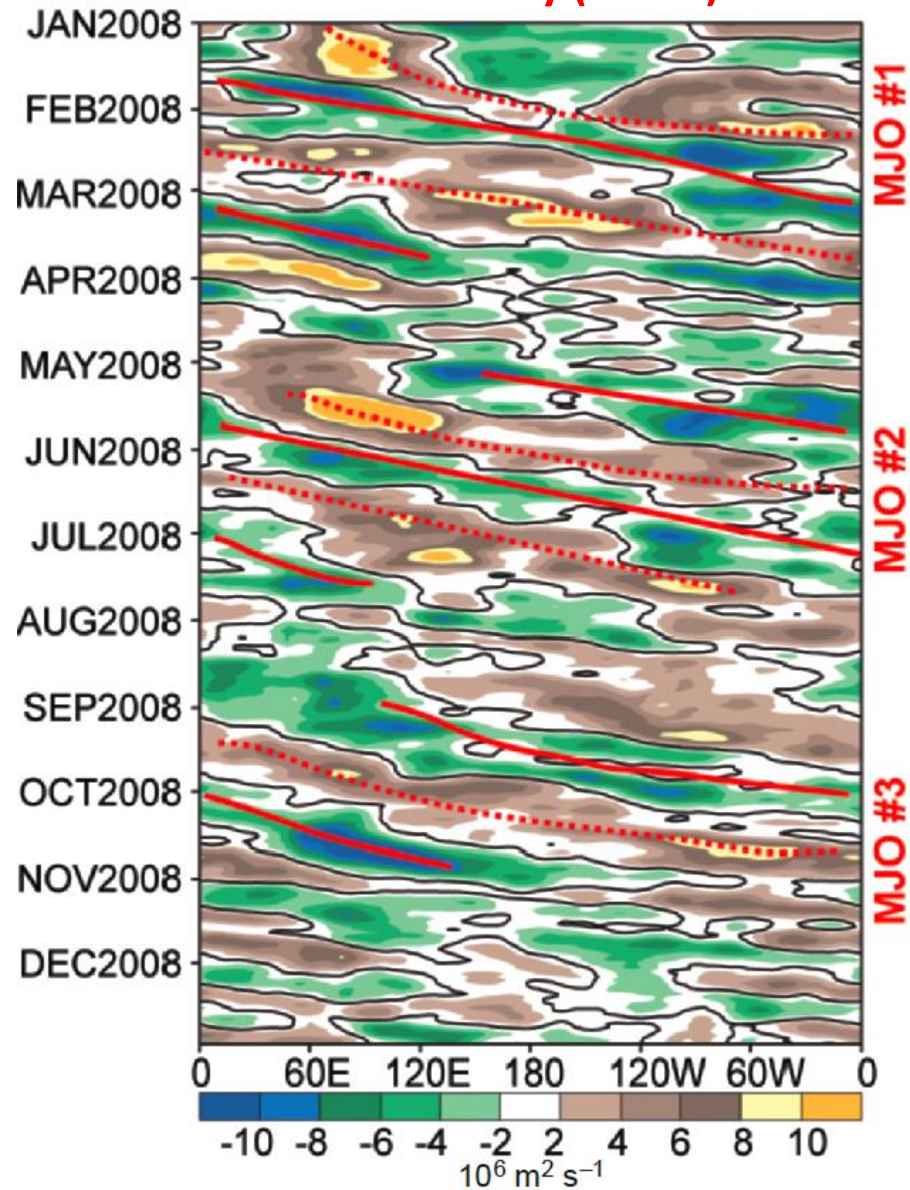
- MJO and La Nina convection out of phase: Negative phase of MJO masks La Nina Convection

CALIPSO/Cloudsat Cloud Frequency of Occurrence Difference Feb08 minus Feb07 (0S–2.5S)





Filtered 200-hPa Velocity Potential Anomaly (5S–5S)



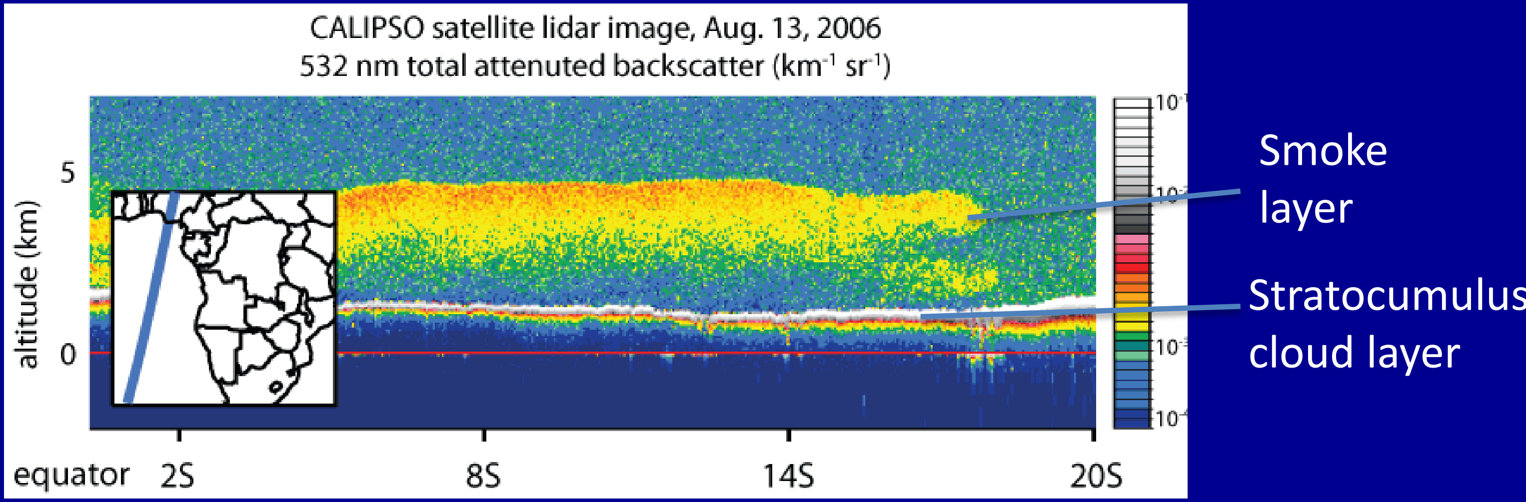
MJO and La Nina convection in phase

Exploring Direct & Semi-Indirect Radiative Effects of Aerosols with A-train Observations

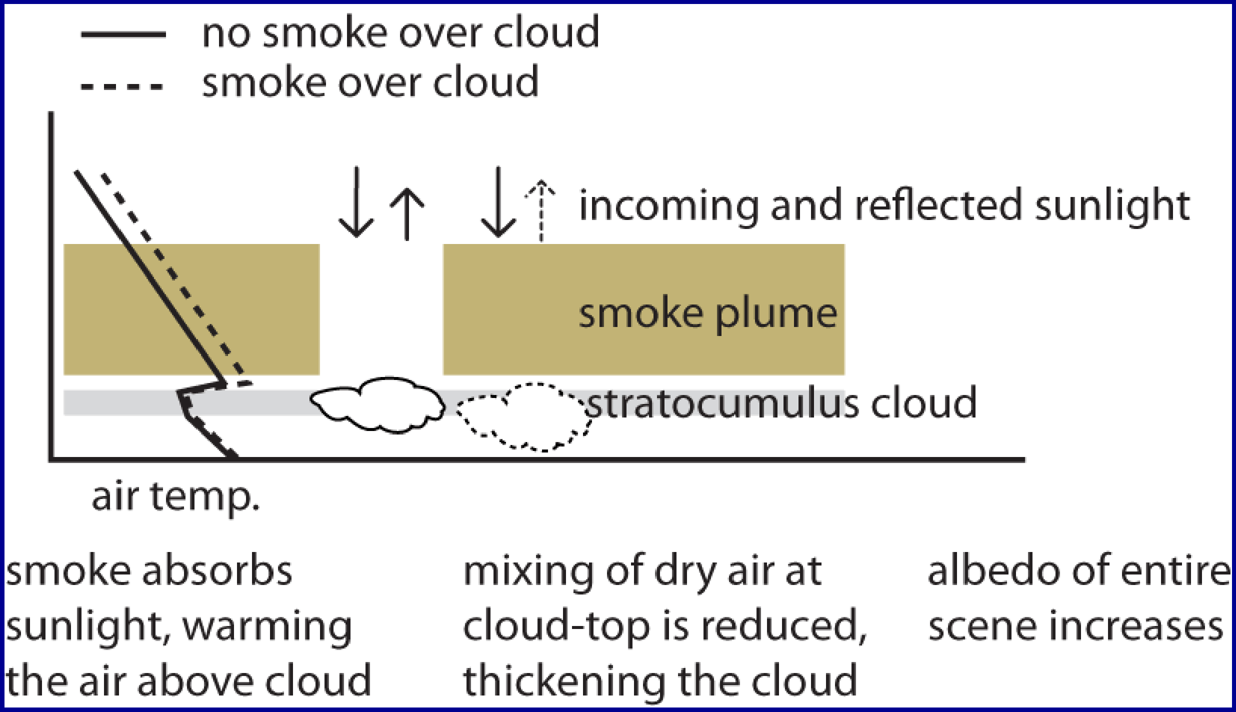
Smoke Over Clouds: Direct and Semi-Direct Aerosol Radiative Forcing

Direct Forcing

When dark smoke resides over bright clouds, the scene darkens - a net warming of local climate.



Semi-Direct Forcing

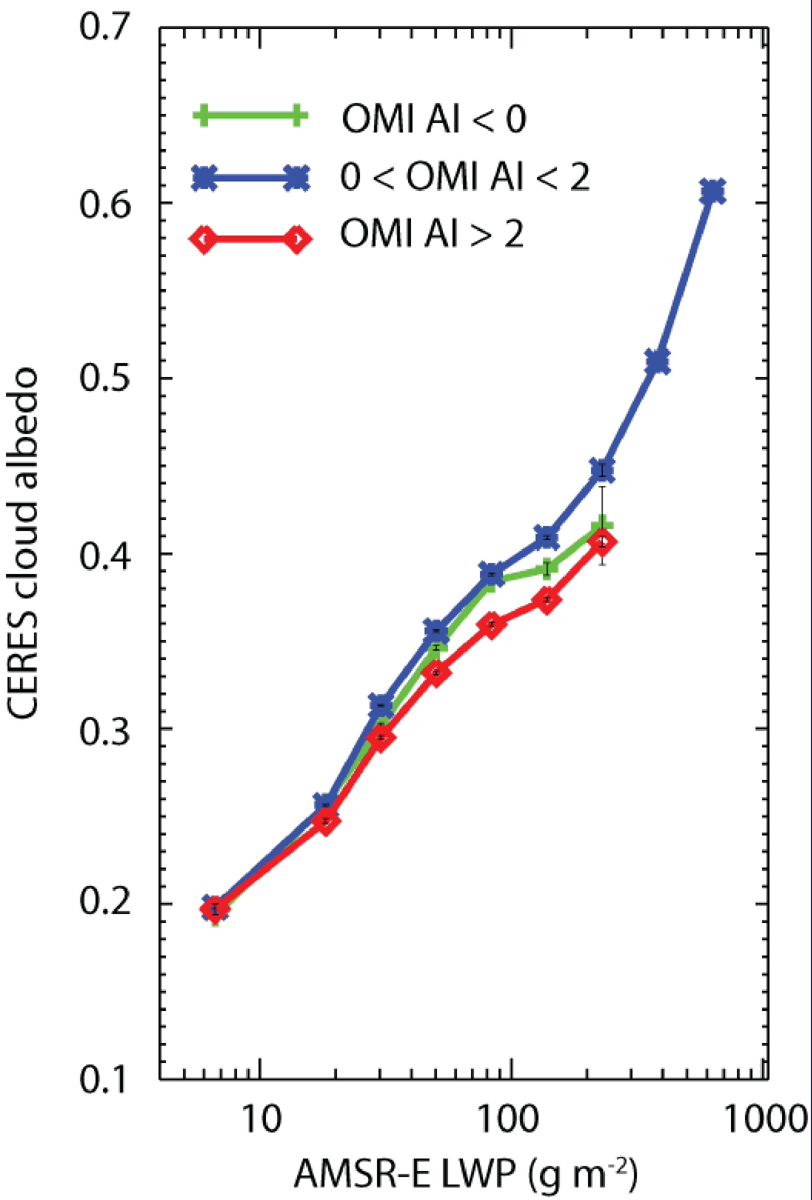


Smoke Over Clouds: Data to Study Impact on Clouds

quantity	Instrument
Aerosol index	OMI
LWP	AMSR-E
SST	AMSR-E
Air temperature	AIRS
Cloud-top temperature	MODIS
Cloud cover	MODIS
Cloud albedo	CERES

- All quantities from Aqua satellite, except for OMI aerosol index on Aura (within a few minutes of the 1:30pm overpass.
- All are averaged over a common 0.25 deg. lat.-lon. Grid.
- 1-km MODIS cloud retrievals are used as a conservative screening for overcast conditions.
- This study focuses on overcast cloud properties – not cloud fraction.
- Cloud-tops colder than 280 K are not included.

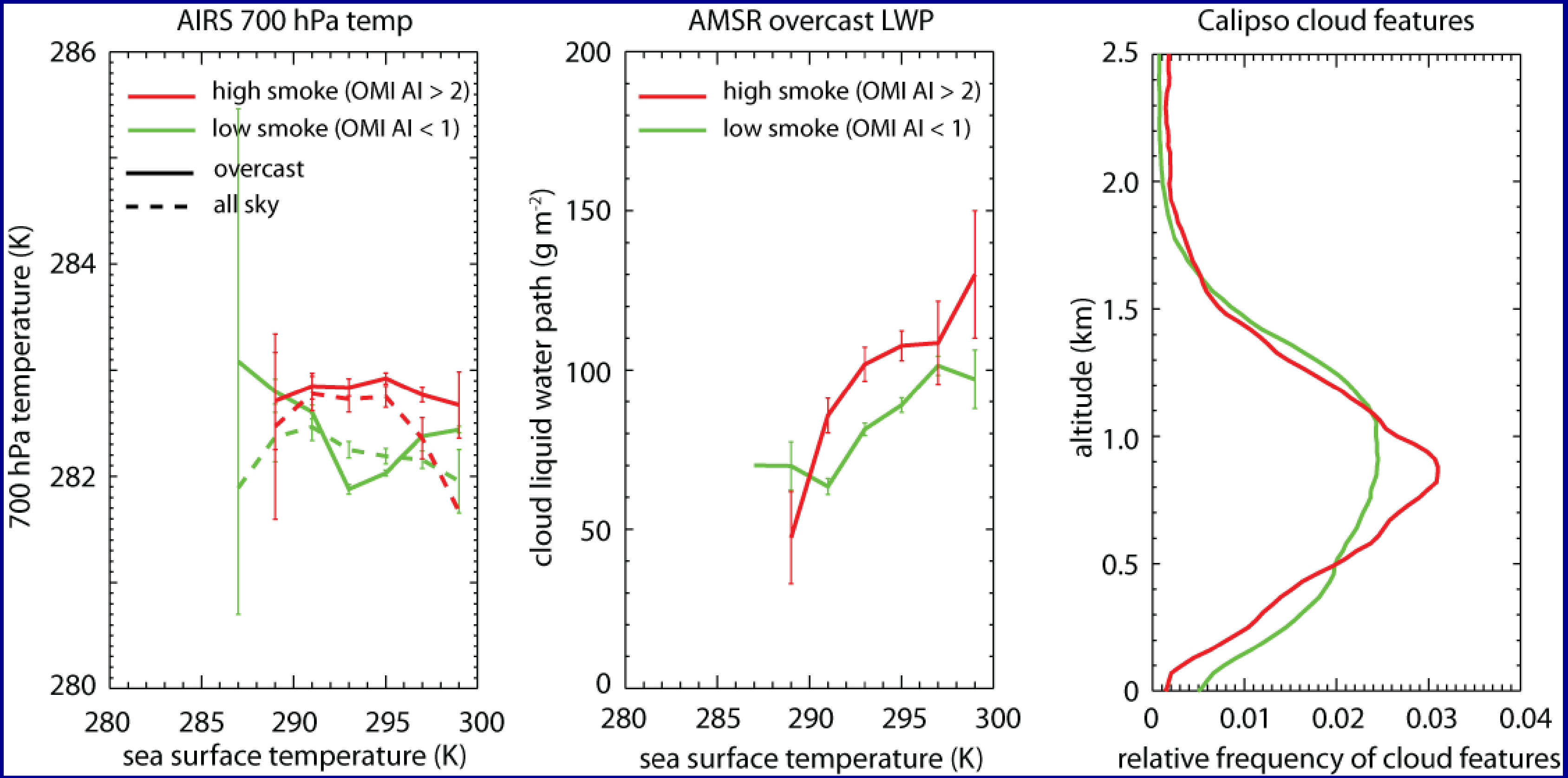
Smoke Over Clouds: Direct Radiative Forcing



- **For overcast conditions the CERES albedo for a given LWP is lower for higher OMI AI (more absorption).**
- **The warming from the direct radiative forcing of smoke is 5 Wm^{-2} on average for overcast conditions.**

Wilcox, E. M., Direct and semi-direct radiative forcing of smoke aerosols over clouds , *in prep.* (2010)

Smoke Over Clouds: Semi-Direct Radiative Forcing



- **Warming of the 700 hPa layer above the cloud-top boundary layer inhibits cloud-top entrainment, (a) preserving boundary layer humidity, (b) enhancing LWP, and (c) promoting subsidence of cloud-top => Consistent with model simulations.**
- **The local cooling due to cloud thickening is -10 Wm^{-2}. Exceeds the direct radiative warming due to dark smoke above bright cloud by a factor of 2.**

Wilcox, E. M., Stratocumulus cloud thickening beneath layers of absorbing smoke aerosol, *ACPD* (2010)

Conclusions

- A-Train instruments are providing new insight about the radiation budget at the top-of-atmosphere, surface and within the atmosphere.
- A-Train is also providing unprecedented detail on coupled aerosol-cloud-precipitation-radiative processes at short time scales (e.g., interannual).
- Continuous monitoring of changes in the Earth's Radiation budget and the associated changes in clouds, aerosols, surface and atmospheric state is what is needed for understanding climate.
- A longer-term global climate-quality data record provides our best constraint on climate model projections, and ultimately policy decisions.
- Can we afford not to continue having A-train class capabilities in the future?